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A SIMPLIFIED RESIDENTIAL BASE-CASE MODEL

A Project for
Texas' Senate Bill 5 Legislation
For Reducing Pollution in
Nonattainment and Affected Areas

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Disclaimer

EXECUTIVE SUMMARY

This study was for the DOE-2.1e program to develop a simplified residential ASHP house model in Houston, Texas. The house characteristics were based on the standard reference design and requirements as defined in Chapter 4 of the 2009 IECC.

To develop the 2009 IECC compliant DOE-2.1e residential house model, this study used the step-by-step procedure started from the "RUN 3A" which is one of the example for a simple structure in the samp1e.inp file included in the DOE-2.1e program package.

The RUN 3A is an office building model, which has 30 degrees of azimuth, 5,000 ft^2 of the floor area with 8 feet of the floor-to-ceiling height and 2 feet of the plenum height. Through the step-by-step procedure, the RUN 3A was modified to become a residential model (i.e., RUN_30 in this study), which has a single-story, a single-family, a south-facing and detached house, which has 2,500 ft^2 of the floor area with 8 feet of the floor-to-ceiling height without the plenum. In addition, the residential base-case model replaced with an ASHP system from a VAV system for RUN 3A.

The step-by-step procedure included six categories: *Project* (7 simulation runs), *ASHP System* (7 simulation runs), *Construction* (9 simulation runs), *Internal Gain* (2 simulation runs), *Schedule* (4 simulation runs), and *DHW* (1 simulation run).

1. *Project Category*: This category modified to simplify building space, building area, window, door size, and occupancy.
2. *System Category*: This category changed building systems from Variable Air Volume (VAV) system to Air-Source Heat Pump (i.e., RESYS in DOE-2.1e) system. This RESYS system sets with the 2009 IECC requirements and with assumption to specify the supply air flow.
3. *Construction Category*: This category modified construction thermal parameters using the 2009 IECC residential reference building requirements.
4. *Internal Gain Category*: This category defined power density for lighting and equipment systems, based on the 2009 IECC residential Standard Reference Design specifications.
5. *Schedule Category*: This category simplified the building schedules for lighting, equipment, infiltration, and internal shading.
6. *Domestic Hot Water (DHW) Category*: This category defined a residential electric DHW heater system.

At the end of the procedure, the annual site energy use for the simplified DOE-2.1e residential base-case model (i.e., the RUN_30) was 70.0 MMBtu/year, including:

- 14.6 MMBtu/year for Area Lights,
- 19.7 MMBtu/year for Equipment,
- 7.6 MMBtu/year for Space Heat,
- 12.4 MMBtu/year for Space Cool,
- 10.8 MMBtu/year for DHW, and
- 4.9 MMBtu/year for Other (i.e., fan and pump).

The results of the DOE-2.1e code-compliant residential building model (i.e., RUN_30 in this study) were compared against the simulation results from other code-compliant simulation programs, which are IC3 and REM/Rate (RESNET, 2013). The results of the total site energy use between all three programs were close, showing the result difference within 1%.

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1 Simplified Residential Base-Case Model

This section presents brief description to develop a simplified residential base-case model with the Air-Source Heat Pump (ASHP), which is located in Houston, TX. The model was based on the standard reference design and requirements as defined in Chapter 4 of the 2009 IECC.

The development procedure began with the "RUN 3A" which is an example for a simple structure in the samp1e.inp file included in the DOE-2.1e program package[1]. Figure 1 shows the 3-D geometry view of the RUN 3A simulation file, which is a single-story, an office building, and 30 degrees azimuth, 5,000 ft^2 of the floor area with an 8 foot floor-to-ceiling height and 2 feet of the plenum height.

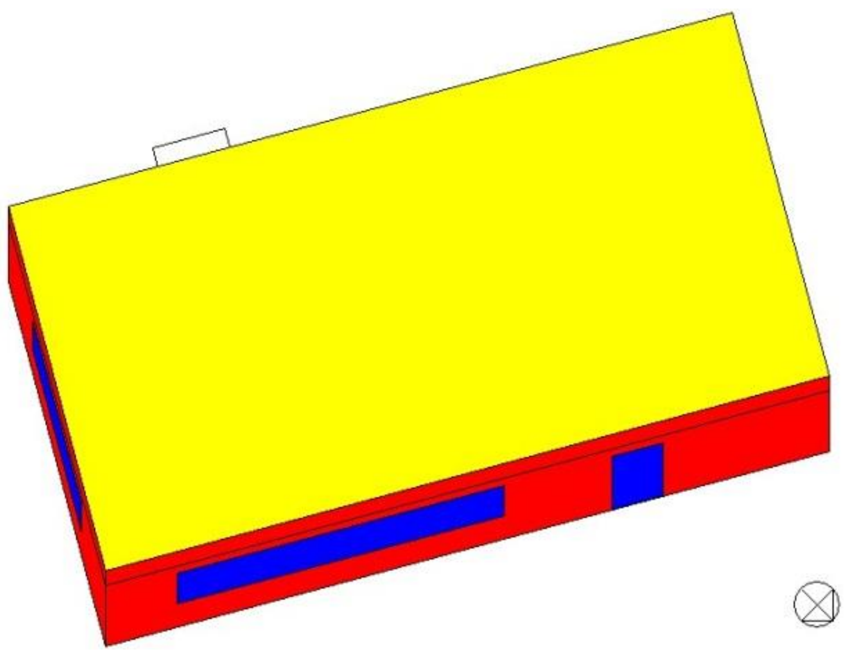

Figure 1: 3-D Geometry View of RUN 3A Model

The residential base-case model to develop in this report is a single-story, a single-family, a south-facing and detached house, which has 2,500 ft^2 of the floor area with an 8 foot floor-to-ceiling height (Figure 2). In addition, the residential base-case model has a simplified structure with a rectangular geometry, a flat roof, and no attic space.

[1] The RUN 3A file can be found in the zip file distributed with this report.

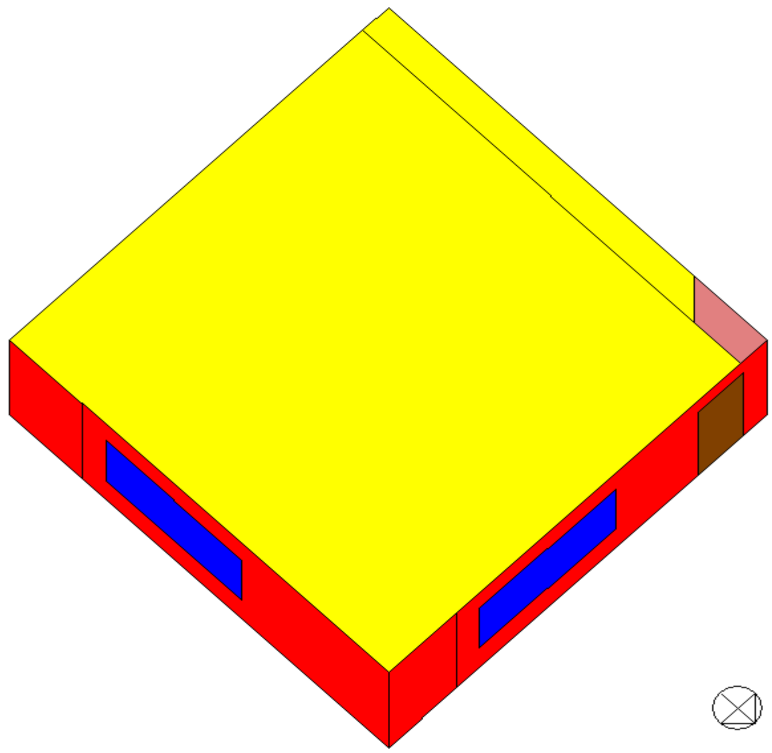

Figure 2: 3-D Geometry View of Simplified Residential DOE-2.1e Base-Case Model

The construction and system characteristics of the residential base-case model were determined from the climate-specific characteristics in the 2009 IECC. In order to develop a simplified residential simulation model, the schedules for space condition (i.e., lighting and equipment) and system operation (i.e., heating, cooling, fan, and infiltration) were set to be continuously on. A residential electric Domestic Hot Water (DHW) heater was installed.

2 Description of the Procedure

The procedure to develop the simplified residential base-case model with an ASHP system consists of six categories (30 simulation runs), including categories for the *Project* (7 simulation runs), the *ASHP System* (7 simulation runs), the *Construction* (9 simulation runs), the *Internal Gain* (2 simulation runs), the *Schedule* (4 simulation runs), and the *DHW* (1 simulation run).

The *Project* category defines general structures for the simplified residential building model. The *ASHP System* category defines input parameters for the ASHP system. The *Construction* category defines input parameters for the residential building envelope based on the 2009 IECC requirements. The *Internal Gain* category defines input parameters for the energy use of the lighting and equipment. The *Schedule* category defines input parameters for simplified schedules for lighting, equipment, infiltration, and interior shading. Finally, the *DHW* category defines an electric DHW system.

Table 1 presents the entire simulation procedure to develop the simplified residential base-case model and summarizes the input parameters for the base-case model. RUN_30 is the final simulation name for this development procedure[2].

[2] The RUN_30 file can be found in the zip file distributed with this report and Appendix D shows the Building Description Language (BDL) inputs for RUN_30.

Table 1: Simulation Procedure for Simplified Residential Base-Case Model

SIMPLIFIED RESIDENTIAL BASE-CASE MODEL																																		
	PROJECT									ASHP SYSTEM							CONSTRUCTION											Internal Gain		SCHEDULE				DHW
Run Name	# of Space	Area	Fenestration (WFR)	Overhang	Azimuth	# of People	Plenum	Return-Air-Path	Door Location	Change System	SEER	HSPF	Fan Schedule	Thermostat Heat	Thermostat Cool	Air Flow Rate	Floor U-Value (Slab-on-Grade)	Roof U-Value	Roof Absorptance	Wall U-Value	Wall Absorptance	Door U-Value	Glazing U-Value	Window Frame	Glazing SHGC	Infiltration ACH	GND Reflec.	Lighting (w/sqft)	Equipment (w/sqft)	Lighting	Equipment	Infiltration	Interior Shading	DHW System
	1	5,000 to 2,500	22% to 15%	Yes to No	30 to 0	52 to 0	Removed	Plenum to Direct	Two (S/N) to Single (N)	VAVS to RESYS	Default to SEER 13	Default to 7.7 HSPF	Schedule to Always	Schedule to 72 F	Schedule to 75 F	7,366 cfm to 1,800 cfm	0.05 to 0.088	0.048 to 0.035	0.7 to 0.75	0.069 to 0.082	0.7 to 0.75	1.142 to 0.65	0.516 to 0.65	None to Frame	0.87 to 0.3	0.25 to 0.35	0 to 0.24	1.5 to 0.1951	1.0 to 0.2632	Schedule to Always	Schedule to Always	Schedule to Always	None to Schedule	None to DHW
RUN_3A	5	5,000	22% WFR	Yes	30	52	Default	Plenum	Two (S/N)	VAVS	7.3	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.47	0.574	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_1	**1**	5,000	22% WFR	Yes	30	52	Default	Plenum	Two (S/N)	VAVS	7.3	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.47	0.574	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_2	1	**2,500**	**15% WFR**	Yes	30	52	Default	Plenum	Two (S/N)	VAVS	7.3	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.47	0.574	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_3	1	2,500	15% WFR	**No**	30	52	Default	Plenum	Two (S/N)	VAVS	7.3	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.47	0.574	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_4	1	2,500	15% WFR	No	**0**	52	Default	Plenum	Two (S/N)	VAVS	7.3	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.47	0.574	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_5	1	2,500	15% WFR	No	0	**0**	Default	Plenum	Two (S/N)	VAVS	7.3	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.47	0.574	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_6	1	2,500	15% WFR	No	0	0	**Removed**	**Direct**	Two (S/N)	VAVS	7.3	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.47	0.574	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_7	1	2,500	15% WFR	No	0	0	Removed	Direct	**Single (N)**	VAVS	7.3	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.47	0.574	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_8	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	**RESYS**	7.3	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_9	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	**13**	5.4	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_10	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	**7.7**	Schedule	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_11	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	**Always**	Schedule	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_12	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	**72**	Schedule	7,366	0.05	0.048	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_13	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	**75**	7,366	0.05	0.048	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_14	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	**1,800**	0.05	0.048	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_15	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	**0.088**	0.048	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_16	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	**0.035**	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_17	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	**0.75**	0.069	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_18	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	**0.082**	0.7	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_19	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	**0.75**	1.142	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_20	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	**0.65**	0.516	None	0.87	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_21	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	**0.65**	**Frame**	**0.3**	0.25	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_22	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	**0.35**	0	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_23	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	0.35	**0.24**	1.5	1.0	Schedule	Schedule	Schedule	None	None
RUN_24	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	0.35	0.24	**0.1951**	1.0	Schedule	Schedule	Schedule	None	None
RUN_25	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	0.35	0.24	0.1951	**0.2632**	Schedule	Schedule	Schedule	None	None
RUN_26	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	0.35	0.24	0.1951	0.2632	**Always**	Schedule	Schedule	None	None
RUN_27	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	0.35	0.24	0.1951	0.2632	Always	**Always**	Schedule	None	None
RUN_28	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	0.35	0.24	0.1951	0.2632	Always	Always	**Always**	None	None
RUN_29	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	0.35	0.24	0.1951	0.2632	Always	Always	Always	**Schedule**	None
RUN_30	1	2,500	15% WFR	No	0	0	Removed	Direct	Single (N)	RESYS	13	7.7	Always	72	75	1,800	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	0.35	0.24	0.1951	0.2632	Always	Always	Always	Schedule	**DHW**

3 Details of the Development Procedure

This section describes the details of the development procedure according to each category. In addition, the Appendix A shows the Building Description Language (BDL) input file modification for each run. The input parameters modified for each simulation through the procedure are highlighted in yellow for Table 2, Table 3, Table 4, Table 5, Table 6, and Table 7.

3.1 Project Category

The first of the six categories, the *Project* category, defines the general building structures for the simplified house, such as number of spaces, area, fenestration, overhang, and orientation. Table 2 shows seven runs in the *Project* category and summarizes the input parameters.

Table 2: Input Summary for the *Project* Category

Run Name	PROJECT								
	# of Space	Area	Fenestration (WFR)	Overhang	Azimuth	# of People	Plenum	Return-Air-Path	Door Location
	1	5,000 to 2,500	22% to 15%	Yes to No	30 to 0	52 to 0	Removed	Plenum to Direct	Two (S/N) to Single (N)
RUN_3A	5	5,000	22% WFR	Yes	30	52	Default	Plenum	Two (S/N)
RUN_1	**1**	5,000	22% WFR	Yes	30	52	Default	Plenum	Two (S/N)
RUN_2	1	**2,500**	**15% WFR**	Yes	30	52	Default	Plenum	Two (S/N)
RUN_3	1	2,500	15% WFR	**No**	30	52	Default	Plenum	Two (S/N)
RUN_4	1	2,500	15% WFR	No	**0**	52	Default	Plenum	Two (S/N)
RUN_5	1	2,500	15% WFR	No	0	**0**	Default	Plenum	Two (S/N)
RUN_6	1	2,500	15% WFR	No	0	0	**Removed**	**Direct**	Two (S/N)
RUN_7	1	2,500	15% WFR	No	0	0	Removed	Direct	**Single (N)**

Each simulation in the *Project* category is described as follows:

- The simplified residential base-case model started from the "RUN_3A", which is included the DOE-2.1e program package. The RUN_3A simulation in this category was modified from the simulation location, from Chicago to Houston. To accomplish this, the latitude was changed to 29.5°, the longitude was changed to 95°, and the altitude set to 68ft for Houston.
- The RUN_1 changed the building space from five zones to a single zone (Table A-1).

- The RUN_2 reduced the building space area from 5,000 ft^2 to 2,500 ft^2 for a typical single-family house. In addition, the fenestration was modified: Window-to-Floor Ratio (WFR) was modified from 22% to 15% and door area was reduced from 113 ft^2 to 40 ft^2, based on Table 405.5.2(1) in 2009 IECC (Table A-2).
- The RUN_3 removed the overhang for the south-facing door (Table A-3).
- The RUN_4 rotated the building orientation faced South (Table A-4).
- The RUN_5 changed the occupancy from 52 to 0 (Table A-5).
- The RUN_6 removed the plenum for the simplified residential model (Table A-6).
- The RUN_7 modified the door size and location, from two doors (on the south wall and the north wall) to a single door (on the north wall only), based on the requirement of Table 405.5.2(1) of the 2009 IECC (Table A-7).

3.2 ASHP System Category

The second of the six categories, the *ASHP System* category, defines the input parameters, such as system efficiency and thermostat setting, for the Air-Source Heat Pump (ASHP) system model from the Variable Air Volume system (VAVS) used in RUN_3A of the SAMP1E.INP file. The ASHP system can be modeled with the residential system type, which is the RESYS system in the DOE-2.1e program. The RESYS system model was created to represent a residential air-to-air heat pump for a single-zone constant-volume system intended for homes or small office. Table 3 shows seven runs in the *ASHP System* category and summarizes the input parameters.

Table 3: Input Summary for the *ASHP System* Category

Run Name	ASHP SYSTEM						
	Change System	SEER	HSPF	Fan Schedule	Thermostat Heat	Thermostat Cool	Air Flow Rate
	VAVS to RESYS	Default to SEER 13	Default to 7.7 HSPF	Schedule to Always	Schedule to 72 F	Schedule to 75 F	7,366 cfm to 1,800 cfm
RUN_8	**RESYS**	7.3	5.4	Schedule	Schedule	Schedule	7,366
RUN_9	RESYS	**13**	5.4	Schedule	Schedule	Schedule	7,366
RUN_10	RESYS	13	**7.7**	Schedule	Schedule	Schedule	7,366
RUN_11	RESYS	13	7.7	**Always**	Schedule	Schedule	7,366
RUN_12	RESYS	13	7.7	Always	**72**	Schedule	7,366
RUN_13	RESYS	13	7.7	Always	72	**75**	7,366
RUN_14	RESYS	13	7.7	Always	72	75	**1,800**

Each simulation in the *ASHP System* category is described as follows:

- The RUN_8 simulation changed the system model, from the Variable Air Volume system (VAVS) to the RESYS system model (Table A-8).
- The RUN_9 simulation defined the cooling efficiency of the ASHP system, from SEER 7.3 to SEER 13, based on Table 503.2.3(2) in 2009 IECC (Table A-9). The cooling Energy Input Ratio (EIR), which excludes the supply air fan energy, was calculated by the following equations. As a result of the above equations, 0.211695 of the cooling EIR was used for the DOE-2.1e input.

$$SEER_{nofan} = 1/(1/SEER–SAFAN)$$

$$EIR_{cooling} = 0.941×(1/(SEER_{nofan}/3.41)$$

Where,

SEER is the seasonal energy efficiency ratio (e.g., a value in 2009 IECC),

SAFAN[3] is the supply air fan energy (Wh/Btu),

$SEER_{nofan}$ is the seasonal energy efficiency ratio that does not include supply fan energy, and

$EIR_{cooling}$ is the cooling energy input ratio.

- The RUN_10 simulation defined the heating efficiency of the ASHP system, from 5.4 HSPF to 7.7 HSPF, based on Table 503.2.3(2) in 2009 IECC (Table A-10). The heating Energy Input Ratio (EIR), which excludes the supply fan energy, was calculated by the following equations. As a result of the above equations, 0.236011 of the heating EIR was used for the DOE-2.1e input.

$$HSPF_{nofan} = 1/(1/HSPF–SAFAN)$$

$$EIR_{heating} = 0.582×(1/(HSPF_{nofan}/3.41)$$

Where,

HSPF is the heating seasonal performance factor (e.g., a value in 2009 IECC),

SAFAN is the supply air fan energy (Wh/Btu),

$HSPF_{nofan}$ is the heating seasonal performance factor that does not include supply fan energy, and

$EIR_{heating}$ is the heating energy input ratio.

- The RUN_11 simulation set the system fan to run when the system runs (Table A-11).
- The RUN_12 simulation set the heating thermostat at a constant 72 F, based on Table 405.5.2(1) in 2009 IECC (Table A-12).

[3] The supply air fan energy was calculated, assuming the supply fan power is 0.365 w/cfm, by the following equation: 0.01095 Wh/Btu = (0.365 W/cfm) × (360 cfm/ton) × (1 ton/12,000 Btu/h)

- The RUN_13 simulation set the cooling thermostat at a constant 75 F, based on Table 405.5.2(1) in 2009 IECC (Table A-13).
- The RUN_14 simulation set the supply air flow from 7,366 cfm to 1,800 cfm, which assumes 360 cfm/ton and 500 ft^2/ton (Table A-14).

3.3 Construction Category

The third of the six categories, the *Construction* category, defines input parameters for the residential building envelope according to the 2009 IECC requirements, including thermal insulation (U-value) of the floor, the roof, the walls, the door, and the windows, and solar absorptance of the roof and the walls. Table 4 shows nine runs in the *Construction* category and summarizes the input parameters.

Table 4: Input Summary for the *Construction* Category

Run Name	CONSTRUCTION										
	Floor U-Value (Slab-on-Grade)	Roof U-Value	Roof Absorptance	Wall U-Value	Wall Absorptance	Door U-Value	Glazing U-Value	Window Frame	Glazing SHGC	Infiltration ACH	Ground Reflectance
	0.05 to 0.088	0.048 to 0.035	0.7 to 0.75	0.069 to 0.082	0.7 to 0.75	1.142 to 0.5	0.516 to 0.65	None to Frame	0.87 to 0.3	0.25 to 0.35	0 to 0.24
RUN_15	**0.088**	0.048	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0
RUN_16	0.088	**0.035**	0.7	0.069	0.7	1.142	0.516	None	0.87	0.25	0
RUN_17	0.088	0.035	**0.75**	0.069	0.7	1.142	0.516	None	0.87	0.25	0
RUN_18	0.088	0.035	0.75	**0.082**	0.7	1.142	0.516	None	0.87	0.25	0
RUN_19	0.088	0.035	0.75	0.082	**0.75**	1.142	0.516	None	0.87	0.25	0
RUN_20	0.088	0.035	0.75	0.082	0.75	**0.65**	0.516	None	0.87	0.25	0
RUN_21	0.088	0.035	0.75	0.082	0.75	0.65	**0.65**	**Frame**	**0.3**	0.25	0
RUN_22	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	**0.35**	0
RUN_23	0.088	0.035	0.75	0.082	0.75	0.65	0.65	Frame	0.3	0.35	**0.24**

Each simulation in the *Construction* category is described as follows:

- The RUN_15 simulation in this category modified the floor thermal insulation. R-0 was used for the slab-on-glade floor in Climate Zone 2, based on Table 402.1.1 in 2009 IECC, using the Winkelmann method (Winkelmann, 1998). The detail of the floor layer input was shown in appendix A (Table A-15).
- The RUN_16 simulation modified the roof thermal insulation. R-30 was used for the roof, based on Section 402.2.2 in the 2009 IECC. IECC. The U-0.035 value was applied to use the layer input

method, including 7% of the framing factor[4]. The roof was divided into two different portions: 93% of the roof area was used for the cavity part and 7% of the roof area was used for the stud part. The detail of the roof layer input was shown in appendix A (Table A-16).

- The RUN_17 simulation modified the roof solar absorptance from 0.7 to 0.75 (Table A-17), based on Table 405.5.2(1) in 2009 IECC.
- The RUN_18 simulation modified the wall thermal insulation for Climate Zone 2 from U-0.069 to U-0.082 (Table A-18), based on Table 402.1.3 in the 2009 IECC. The U-0.082 was applied to use the layer input method, including 25% of the framing factor. Each exterior wall was divided into two different parts: 75% of the wall area was used for the cavity part and 25% of the wall area was used for the stud part. The detail of the exterior wall layer input was shown in appendix A (Table A-18).
- The RUN_19 simulation modified the wall solar absorptance from 0.7 to 0.75 (Table A-19), based on Table 405.5.2(1) in the 2009 IECC.
- The RUN_20 simulation modified the door thermal insulation from U-1.142 to U-0.65 (Table A-20), based on Table 303.1.3(2) in the 2009 IECC.
- The RUN_21 simulation modified the window glass thermal conductance and Solar Heat Gain Coefficient[5] (SHGC) for Climate Zone 2 from U-0.516 to U-0.65 and from 0.87 to 0.3 (Table A-21), based on Table 402.1.3 in the 2009 IECC. In addition, an aluminum window frame was added.
- The RUN_22 simulation modified the infiltration rate from 0.2916 Air Changes per Hour (ACH) to 0.35 ACH (Table A-22), based on Table 405.5.2(1) in the 2009 IECC. In order to input the infiltration, this study used 0.0004321 of the Specific Leakage Area (SLA) value, which was calculated by the following equation (EnergyGauge, 2008):

  $$ACH = SLA \times 1{,}000 \times W \times NS^{0.3}$$

  Where,

  ACH is the air change per hour,

  SLA is the specific leakage area,

  W is the weather factor; 0.81was used for Houston (ASHRAE, 2006), and

  NS is the number of stories above grade.
- The RUN_23 simulation modified the ground reflectance from 0 for the exterior walls and 0.2 for the roof to 0.24 for both the walls and roof (Table A-23). 0.24 of the ground reflectance represents the residential building is surrounded by grass.

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[4] Framing factor represents the percentage of stud or joist area.
[5] Shading Coefficient (SC) = SHGC / 0.87

3.4 Internal Gain Category

Fourth of the six categories, the *Internal Gain* category, defines input parameters for the energy use of the lighting and the equipment. Table 5 shows two runs in the *Internal Gain* category and summarizes the input parameters.

Table 5: Input Summary for the *Internal Gain* Category

Run Name	Internal Gain	
	Lighting (w/sqft)	Equipment (w/sqft)
	1.5 to 0.1951	1.0 to 0.2632
RUN_24	**0.1951**	1.0
RUN_25	0.1951	**0.2632**

The values of the power density (W/ft^2) for the lighting and the equipment were calculated, using the following internal gains (IGain) equation from Table 405.5.2(1) in the 2009 IECC.

$$IGain = 17{,}900 + 23.8 \times CFA + 4{,}104 \times N_{br}$$

Where,

CFA is the conditioned floor area (ft^2); 2,500 ft^2 was used in this study, and

N_{br} is the number of bedrooms; four bedrooms were used.

Based on the calculation, the internal gains were 89,712 Btu/day (27.49 kWh/day), which is equivalent to 3,738 Btu/hr (1.145 kWh/hr). To determine the distribution from the calculated internal gains to the Lighting and Equipment power density, the annual appliance and equipment loads in the Building America Research Benchmark were referenced (NREL, 2005). Assuming 100% incandescent interior lighting, about 42.6% of the total internal gains resulted from lighting use and the rest of the total internal gains resulted from equipment use. Therefore, lighting power density and equipment power density for the residential model set 0.1951 W/ft^2 and 0.2632 W/ft^2, respectively.

As a result, each simulation in the *Internal Gain* category is described as follows:

- The RUN_24 simulation in this category modified the lighting power density from 1.5 W/ft^2 to 0.1951 W/ft^2 (Table A-24).

- The RUN_25 simulation in this category modified the equipment power density from 1.0 W/ft^2 to 0.2632 W/ft^2 (Table A-25).

3.5 Schedule Category

Fifth of the six categories, the *Schedule* category, defines input parameters for the residential model to have constant schedules for lighting, equipment, and infiltration. In addition, the *Schedule* category defines the interior shading. Table 6 shows four runs in the *Schedule* category and summarizes the input parameters.

Table 6: Input Summary for the *Schedule* Category

Run Name	SCHEDULE			
	Lighting	Equipment	Infiltration	Interior Shading
	Schedule to Always	Schedule to Always	Schedule to Always	None to Schedule
RUN_26	**Always**	Schedule	Schedule	None
RUN_27	Always	**Always**	Schedule	None
RUN_28	Always	Always	**Always**	None
RUN_29	Always	Always	Always	**Schedule**

Each simulation in the *Schedule* category is described as follows:

- The RUN_26 simulation in this category set the lighting system to be always on (Table A-26).
- The RUN_27 simulation in this category set the equipment system to be always on (Table A-27).
- The RUN_28 simulation in this category set the infiltration to be always on (Table A-28). However, it should be noted that the infiltration schedule does not work for the Sherman-Grimsrud (S-G) method in the DOE-2.1e program.
- The RUN_29 simulation in this category set the schedule of the interior shading[6] for the windows based on Table 405.5.2(1) in the 2009 IECC (Table A-29). 0.85 and 0.7 were used for winter and summer interior shading, respectively.

[6] Interior shading represents percentage of light transmitted from outside to inside through blinds or drapes operation. The multipliers in the interior shading schedule are specified in terms of: 1.0 means no shading, 0.0 means full shading.

3.6 DHW Category

Finally, the last category is the *DHW* category, which defines input parameters for a residential electric domestic hot water (DHW) system, in Table 7. The residential DHW model in this study has 50 gallons of the hot water tank size and 18,766 Btu/hr of the burner capacity (NREL, 2008). A 1.0 was used for the energy factor for the electric water heater, which is the default value of the DOE-2.1e program. To estimate the hot water consumption, the following equation was used. As a result, 0.0486 gal/min of the hot water consumption was determined.

$$\text{HW consumption (gal/min)} = (30 + (10\times N_{br})) / 1{,}440$$

Where,

N_{br} is the number of bedrooms; four bedrooms were assumed.

Table 7: Input Summary for the *DHW* Category

Run Name	DHW
	DHW System
	None to DHW
RUN_30	DHW

In addition, the IC3 DHW inlet water temperatures, which was calculated using Equation 5 in the NREL report (NREL, 2004), were referenced. The resulted water inlet temperatures are shown in Figure A-8.

- The RUN_30 simulation in this category defined the residential electric DHW heater system (Table A-30).

4 Results of the Simplified Residential Base-Case Model

This section presents energy use analysis resulted from the DOE-2.1e simulations following the residential model development procedure. The energy use results are described with six sectors: total, area lights, miscellaneous equipment, space heat, space cool, and others which include the energy use from heat rejection for the variable air volume (VAV) system, pumps and ventilation fans.

Table 8 shows the summary table of the annual site energy use for each simulation, including description of the key modification. Figure 3 shows the plot of the site energy use change for each sector throughout the procedure.

Table 8: Summary Table for the Simulation results of the Procedure

Category	Run Name	Key Modification	Area Lights (MMBtu/yr)	Equipment (MMBtu/yr)	Space Heat (MMBtu/yr)	Space Cool (MMBtu/yr)	DHW (MMBtu/yr)	Fan+Pump (MMBtu/yr)	TOTAL (MMBtu/yr)
Project	RUN_3A	RUN3A located in Houston	74.5	44.6	8.7	72.1	0.0	39.7	239.6
	RUN_1	From five spaces to single space	74.5	44.6	6.8	73.5	0.0	40.8	240.2
	RUN_2	Reduced space area/Adjusted fenestration	37.2	22.3	10.2	53.2	0.0	27.2	150.1
	RUN_3	Overhang removed	37.2	22.3	10.1	53.3	0.0	27.3	150.2
	RUN_4	Orientation to south	37.2	22.3	9.7	53.0	0.0	26.9	149.1
	RUN_5	Number of occupancy from 52 to 0	37.2	22.3	22.1	45.8	0.0	24.0	151.4
	RUN_6	Plenum removed	37.2	22.3	21.7	45.5	0.0	23.8	150.5
	RUN_7	Door size and location	37.2	22.3	23.3	45.3	0.0	23.8	151.9
ASHP System	RUN_8	Mechanical system from VAVS to ASHP	37.2	22.3	0.3	37.3	0.0	25.8	122.9
	RUN_9	Cooling efficiency	37.2	22.3	0.3	18.0	0.0	25.8	103.6
	RUN_10	Heating efficiency	37.2	22.3	0.2	18.0	0.0	25.8	103.5
	RUN_11	Fan schedule	37.2	22.3	0.1	17.5	0.0	24.3	101.4
	RUN_12	Thermostat heating set point	37.2	22.3	1.4	17.7	0.0	25.1	103.7
	RUN_13	Thermostat cooling set point	37.2	22.3	2.4	31.9	0.0	77.9	171.7
	RUN_14	Supply air flow	37.2	22.3	2.7	23.7	0.0	9.6	95.5
Construction	RUN_15	Floor insulation	37.2	22.3	5.8	20.9	0.0	8.9	95.1
	RUN_16	Roof insulation	37.2	22.3	4.9	20.1	0.0	8.5	93.0
	RUN_17	Roof absorptance	37.2	22.3	4.9	20.2	0.0	8.5	93.1
	RUN_18	Wall insulation	37.2	22.3	4.6	20.0	0.0	8.4	92.5
	RUN_19	Wall absorptance	37.2	22.3	4.6	20.1	0.0	8.4	92.6
	RUN_20	Door insulation	37.2	22.3	4.5	19.7	0.0	8.2	91.9
	RUN_21	Glass conductance/SHGC/Frame	37.2	22.3	5.5	15.2	0.0	6.6	86.8
	RUN_22	Infiltration	37.2	22.3	7.2	18.0	0.0	7.0	91.7
	RUN_23	Ground reflectance	37.2	22.3	7.1	18.3	0.0	7.1	92.0
Internal Gain	RUN_24	Lighting power density	4.8	22.3	8.6	12.9	0.0	5.3	53.9
	RUN_25	Equipment power density	4.8	5.9	9.8	10.5	0.0	4.7	35.7
Schedule	RUN_26	Lighting schedule	14.6	5.9	8.7	11.7	0.0	4.9	45.8
	RUN_27	Equipment schedule	14.6	19.7	7.4	13.5	0.0	5.3	60.5
	RUN_28	Infiltration schedule	14.6	19.7	7.4	13.5	0.0	5.3	60.5
	RUN_29	Interior shading schedule	14.6	19.7	7.6	12.4	0.0	4.9	59.2
DHW	RUN_30	DHW system	14.6	19.7	7.6	12.4	10.8	4.9	70.0

The total site energy use for the RUN_3A was 239.6 MMBtu/year, including:

- 74.5 MMBtu/year for Area Lights,
- 44.6 MMBtu/year for Equipment,
- 8.7 MMBtu/year for Space Heat,
- 72.1 MMBtu/year for Space Cool, and
- 39.7 MMBtu/year for Other (i.e., fan and pump).

Throughout the procedure, the total site energy use for the RUN_30 was 70.0 MMBtu/year, including:

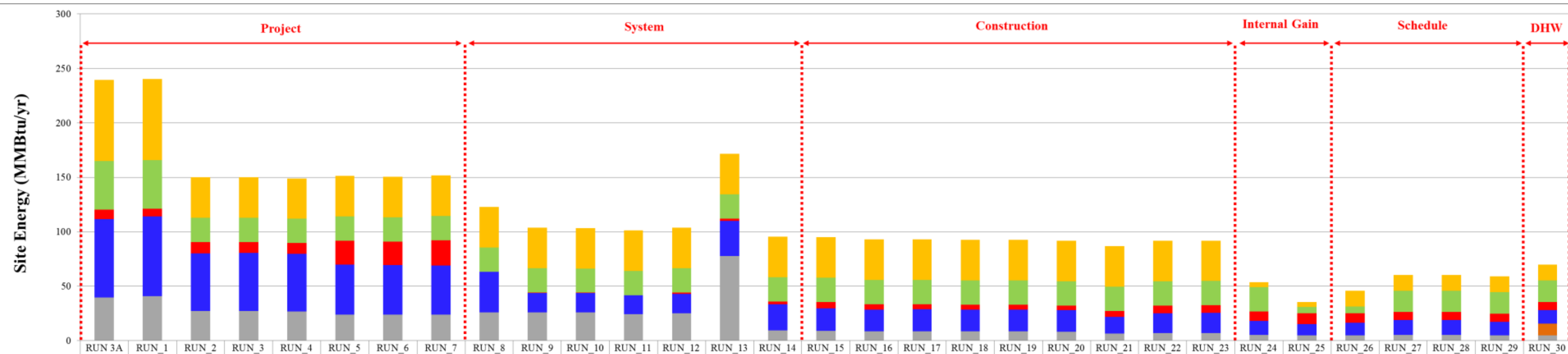
- 14.6 MMBtu/year for Area Lights,
- 19.7 MMBtu/year for Equipment,
- 7.6 MMBtu/year for Space Heat,
- 12.4 MMBtu/year for Space Cool,
- 10.8 MMBtu/year for DHW, and
- 4.9 MMBtu/year for Other (i.e., fan and pump).

Figure 4 shows the plot of the percentage change for each sector's energy use of the total energy use throughout the procedure. From the RUN_3A to the RUN_30, the percentage of the energy distribution changes for each sector is:

- From 31.1% to 20.9% for Area Lights,
- From 18.6% to 28.1% for Equipment,
- From 3.6% to 10.1% for Space Heat,
- From 30.1% to 17.7% for Space Cool,
- From 0% to 15.4% for DHW, and
- From 16.6% to 7.0% for Other (i.e., fan and pump).

Figure 5 shows the Energy Use Intensity (EUI) changes throughout the procedure. From the RUN_3A to the RUN_30, the EUI changes for each sector are:

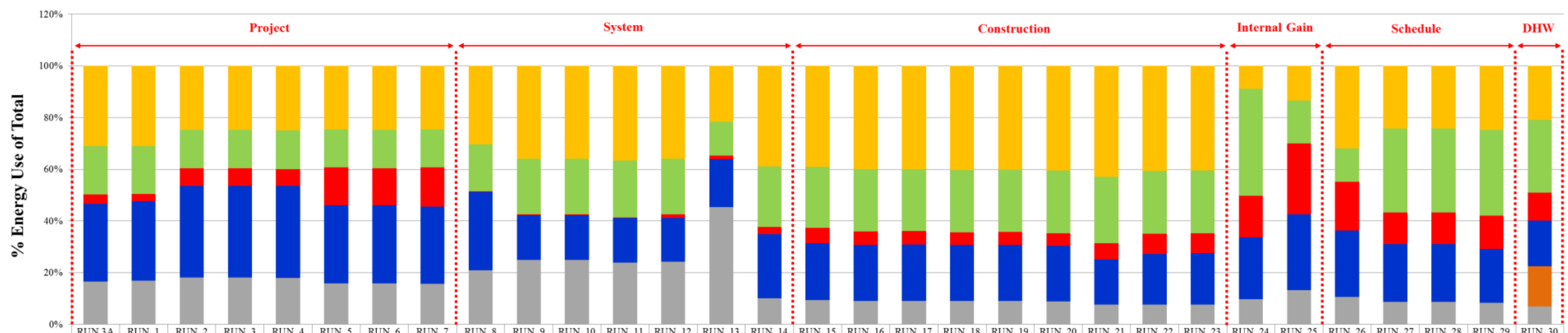
- From 14.9 kBtu/year-ft^2 to 5.8 kBtu/year-ft^2 for Area Lights,
- From 8.9 kBtu/year-ft^2 to 7.9 kBtu/year-ft^2 for Equipment,
- From 1.7 kBtu/year-ft^2 to 3.0 kBtu/year-ft^2 for Space Heat,
- From 14.4 kBtu/year-ft^2 to 5.0 kBtu/year-ft^2 for Space Cool,
- From 0 kBtu/year-ft^2 to 4.3 kBtu/year-ft^2 for DHW, and
- From 7.9 kBtu/year-ft^2 to 2.0 kBtu/year-ft^2 for Other (i.e., fan and pump).



	RUN 3A	RUN_1	RUN_2	RUN_3	RUN_4	RUN_5	RUN_6	RUN_7	RUN_8	RUN_9	RUN_10	RUN_11	RUN_12	RUN_13	RUN_14
TOTAL	239.6	240.2	150.1	150.2	149.1	151.4	150.5	151.9	122.9	103.6	103.5	101.4	103.7	171.7	95.5
Area Lights	74.5	74.5	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2
Equipment	44.6	44.6	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3
Space Heat	8.7	6.8	10.2	10.1	9.7	22.1	21.7	23.3	0.3	0.3	0.2	0.1	1.4	2.4	2.7
Space Cool	72.1	73.5	53.2	53.3	53.0	45.8	45.5	45.3	37.3	18.0	18.0	17.5	17.7	31.9	23.7
DHW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fan+Pump	39.7	40.8	27.2	27.3	26.9	24.0	23.8	23.8	25.8	25.8	25.8	24.3	25.1	77.9	9.6

	RUN_15	RUN_16	RUN_17	RUN_18	RUN_19	RUN_20	RUN_21	RUN_22	RUN_23	RUN_24	RUN_25	RUN_26	RUN_27	RUN_28	RUN_29	RUN_30
TOTAL	95.1	93.0	93.1	92.5	92.6	91.9	86.8	91.7	92.0	53.9	35.7	45.8	60.5	60.5	59.2	70.0
Area Lights	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	4.8	4.8	14.6	14.6	14.6	14.6	14.6
Equipment	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	5.9	5.9	19.7	19.7	19.7	19.7
Space Heat	5.8	4.9	4.9	4.6	4.6	4.5	5.5	7.2	7.1	8.6	9.8	8.7	7.4	7.4	7.6	7.6
Space Cool	20.9	20.1	20.2	20.0	20.1	19.7	15.2	18.0	18.3	12.9	10.5	11.7	13.5	13.5	12.4	12.4
DHW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8
Fan+Pump	8.9	8.5	8.5	8.4	8.4	8.2	6.6	7.0	7.1	5.3	4.7	4.9	5.3	5.3	4.9	4.9

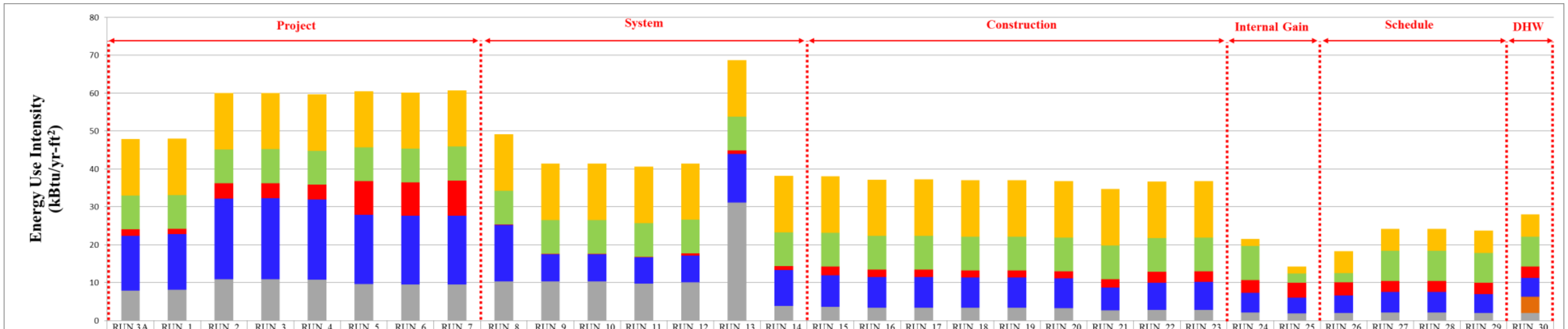
Figure 3: Site Energy Use of the Simulation Results



	RUN 3A	RUN_1	RUN_2	RUN_3	RUN_4	RUN_5	RUN_6	RUN_7	RUN_8	RUN_9	RUN_10	RUN_11	RUN_12	RUN_13	RUN_14
TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Area Lights	31.1%	31.0%	24.8%	24.8%	24.9%	24.6%	24.7%	24.5%	30.3%	35.9%	35.9%	36.7%	35.9%	21.7%	39.0%
Equipment	18.6%	18.6%	14.9%	14.8%	15.0%	14.7%	14.8%	14.7%	18.1%	21.5%	21.5%	22.0%	21.5%	13.0%	23.4%
Space Heat	3.6%	2.8%	6.8%	6.7%	6.5%	14.6%	14.4%	15.3%	0.2%	0.3%	0.2%	0.1%	1.4%	1.4%	2.8%
Space Cool	30.1%	30.6%	35.4%	35.5%	35.5%	30.3%	30.2%	29.8%	30.3%	17.4%	17.4%	17.3%	17.1%	18.6%	24.8%
DHW	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fan+Pump	16.6%	17.0%	18.1%	18.2%	18.0%	15.9%	15.8%	15.7%	21.0%	24.9%	24.9%	24.0%	24.2%	45.4%	10.1%

	RUN_15	RUN_16	RUN_17	RUN_18	RUN_19	RUN_20	RUN_21	RUN_22	RUN_23	RUN_24	RUN_25	RUN_26	RUN_27	RUN_28	RUN_29	RUN_30
TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Area Lights	39.1%	40.0%	40.0%	40.2%	40.2%	40.5%	42.9%	40.6%	40.4%	8.9%	13.4%	31.9%	24.1%	24.1%	24.7%	20.9%
Equipment	23.4%	24.0%	24.0%	24.1%	24.1%	24.3%	25.7%	24.3%	24.2%	41.4%	16.5%	12.9%	32.6%	32.6%	33.3%	28.1%
Space Heat	6.1%	5.3%	5.3%	5.0%	5.0%	4.9%	6.3%	7.9%	7.7%	16.0%	27.5%	19.0%	12.2%	12.2%	12.8%	10.9%
Space Cool	22.0%	21.6%	21.7%	21.6%	21.7%	21.4%	17.5%	19.6%	19.9%	23.9%	29.4%	25.5%	22.3%	22.3%	20.9%	17.7%
DHW	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.4%
Fan+Pump	9.4%	9.1%	9.1%	9.1%	9.1%	8.9%	7.6%	7.6%	7.7%	9.8%	13.2%	10.7%	8.8%	8.8%	8.3%	7.0%

Figure 4: Percentage Change of Each Sector’s Energy Use throughout the Procedure



	RUN 3A	RUN_1	RUN_2	RUN_3	RUN_4	RUN_5	RUN_6	RUN_7	RUN_8	RUN_9	RUN_10	RUN_11	RUN_12	RUN_13	RUN_14
TOTAL	47.9	48.0	60.0	60.1	59.6	60.6	60.2	60.8	49.2	41.4	41.4	40.6	41.5	68.7	38.2
Area Lights	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
Equipment	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Space Heat	1.7	1.4	4.1	4.0	3.9	8.8	8.7	9.3	0.1	0.1	0.1	0.0	0.6	1.0	1.1
Space Cool	14.4	14.7	21.3	21.3	21.2	18.3	18.2	18.1	14.9	7.2	7.2	7.0	7.1	12.8	9.5
DHW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fan+Pump	7.9	8.2	10.9	10.9	10.8	9.6	9.5	9.5	10.3	10.3	10.3	9.7	10.0	31.2	3.8

	RUN_15	RUN_16	RUN_17	RUN_18	RUN_19	RUN_20	RUN_21	RUN_22	RUN_23	RUN_24	RUN_25	RUN_26	RUN_27	RUN_28	RUN_29	RUN_30
TOTAL	38.0	37.2	37.2	37.0	37.0	36.8	34.7	36.7	36.8	21.6	14.3	18.3	24.2	24.2	23.7	28.0
Area Lights	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	1.9	1.9	5.8	5.8	5.8	5.8	5.8
Equipment	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	2.4	2.4	7.9	7.9	7.9	7.9
Space Heat	2.3	2.0	2.0	1.8	1.8	1.8	2.2	2.9	2.8	3.4	3.9	3.5	3.0	3.0	3.0	3.0
Space Cool	8.4	8.0	8.1	8.0	8.0	7.9	6.1	7.2	7.3	5.2	4.2	4.7	5.4	5.4	5.0	5.0
DHW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3
Fan+Pump	3.6	3.4	3.4	3.4	3.4	3.3	2.6	2.8	2.8	2.1	1.9	2.0	2.1	2.1	2.0	2.0

Figure 5: Energy Use Intensity of the Simulation Results

5 Comparative Study

In order to check a validity of the RUN_30 results, the IC3 and REM/Rate programs were used by comparing the RUN_30 simulation results against the programs. The base-case models for IC3 and REM/Rate were developed using input parameters of the RUN_30. Table 9 summarizes the input for the RUN_30 in the two programs (i.e., IC3 and REM/Rate). In addition, the screenshots of the input parameter setting for IC3 and REM/Rate can be found in the appendix B and the appendix C, respectively.

Table 9: Input for the Base-Case House in IC3, REM/Rate, and DOE-2.1e: Houston, TX

Input/Default		IC3	REM / Rate	DOE-2.1e (RUN_30)
PROJECT				
# of Bedrooms		4		
# of People		0	-	0
# of Stories		1		
Building Azumith		South	-	South
Conditioned Area	(sqft)	2,500		
Average Wall Height	(ft)	8		
Conditioned Volume	(cuft)	20,000		
Housing type		Single Family Detached		
CLIMATE				
Location		Houston		
Weather File		TMY2	Combination of TMY2 & TMY3	TMY2
FLOORS				
Type		Slab-on-grade		
R-value	(hr-sqft-F/Btu)	R-0		
Floor Covering		20% Tile, 80% Carpet	100% Carpet	20% Tile, 80% Carpet
Area	(sqft)	2,500		
Full Perimeter	(ft)	200		
Depth below Grade	(ft)	0		
Total Exposed Perimeter	(ft)	200		
On-Grade Exposed Perimeter	(ft)	200		
ROOF				
Roofing Material		Composition Shingle		
Roof Emissivity		0.9	-	0.9
Absorptance		0.75	0.75 (Medium Color)	0.75
Radiant Barrier		No		
Roof Insulation	(hr-sqft-F/Btu)	R-0		
Slope	(Degrees)	0		
Clay or Concrete Roofing		-	No	-
Sub-Tile Ventilation		-	No	-
CEILING				
Type		Cathedral	-	-
R-value	(hr-sqft-F/Btu)	R-27.8	R-28.0	R-27.8
Equivalent U-value	(Btu/hr-sqft-F)	U-0.035		
Framing Factor		0.07		
Area	(sqft)	2,500		

Table 9: Input for the Base-Case House in IC3, REM/Rate, and DOE-2.1e: Houston, TX (Cont.)

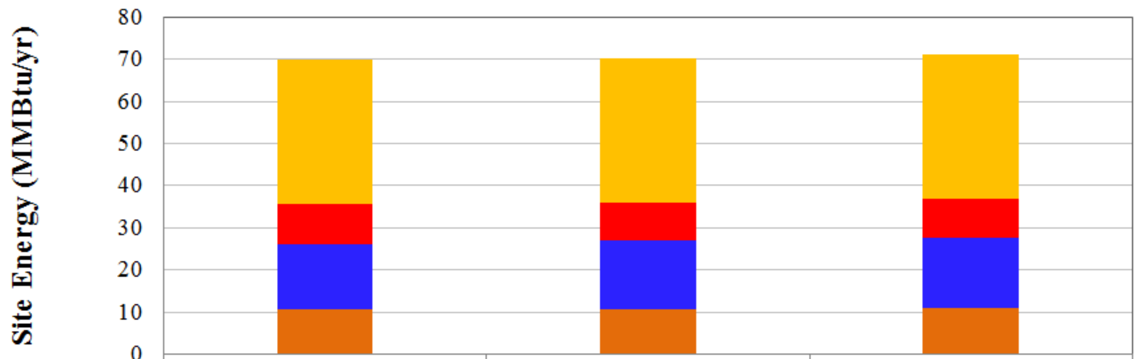
Input/Default		IC3	REM / Rate	DOE-2.1e (RUN_30)
WALLS				
Insulation	(hr-sqft-F/Btu)	R-11.8	R-12.1	R-11.8
Equivalent U-value	(Btu/hr-sqft-F)	0.082		
Framing Factor		0.25		
Sheathing R-value	(hr-sqft-F/Btu)	0	-	-
Absorptance		0.75	0.75 (Medium Color)	0.75
(Width x Height) x Number	(sqft)	(50 x 8) x 4		
Exterior Finish		Brick		
Location		Between Conditioned Space and Ambient		
DOORS				
Orientation		North, South	North	North
Area for each	(sqft)	20	40	40
R-value	(hr-sqft-F/Btu)	1.54		
Equivalent U-value	(Btu/hr-sqft-F)	0.65		
Storm Door		No		
WINDOWS & SHADING				
U-value	(Btu/hr-sqft-F)	0.65		
SHGC		0.3		
No. of Panes		1	-	1
Frame Type		Aluminum w/o Thermal Break	-	Aluminum w/o Thermal Break
Frame Conductance	(Btu/hr-sqft-F)	3.037	-	3.037
Window Area	(sqft)	93.75 x 4		
Orientation		East, West, South, & North		
Overhang		None		
Interior Shade Winter		0.85		
Interior Shade Summer		0.7		
Adjacent Shading		None		
INFILTRATION				
Measurement Type		Blower Door	Blower Door	-
Specific Leakage Area		0.0004321		
Shielding Coefficient		0.24	0.24 (Shelter Class 3)	0.24
2009 IECC Verification		-	Tested	-
Mechanical Ventilation		No		
COOLING				
Type		Electric		
System Type		ASHP		
SHR (SV-A)		0.687		
Efficiency		SEER 13		
Capacity	(kBtu/hr)	60		
Location		Conditioned Space		
Supply CFM	(CFM/ ton)	360	-	360
HEATING				
Fuel Type		Electric		
Heating Type		ASHP		
Efficiency		7.7 HSPF		
Capacity	(kBtu/hr)	60		
Location		Conditioned Space		
Auxiliary Energy Source		Electric		
Auxiliary Energy Use	(kWh)	-	Default	-

Table 9: Input for the Base-Case House in IC3, REM/Rate, and DOE-2.1e: Houston, TX (Cont.)

Input/Default		IC3	REM / Rate	DOE-2.1e (RUN_30)
DUCTS				
Supply R-value	(hr-sqft-F/Btu)	8	8	-
Return R-value	(hr-sqft-F/Btu)	6	6	-
Supply Duct Area	(sqft)	675	675	-
Return Duct Area	(sqft)	125	125	-
# Return		1	1	-
Duct Location		Conditioned Space		
Use Measured Leakage		-	Yes (CFM@25Pa)	-
Leakage to Outside		-	0	-
Total Duct Leakage		-	0	-
HOT WATER				
Type		Electric		
Rated Input	(Btu/hr)	18,766	-	18,766
Capacity	(Gallons)	50		
Water Usage	(Gallons/Day)	70		
Energy Factor		1	0.98	1
Temperature Settings	(F)	120	-	120
THERMOSTAT SETTING				
Cooling	(F)	75		
Heating	(F)	72		
APPLIANCES & LIGHTS				
Schedule		Constant		
Lighting	(kW)	0.49		
Equipment	(kW)	0.66		

To compare the REM/Rate simulation results against the IC3 and RUN_30 simulation results, this study calculated the distribution ratio for the pump and fan energy use based on the cooling and heating energy use ratio. The reason is that the REM/Rate program does not provide the pump and fan energy use separately, but the pump and fan energy use is already included in the heating and cooling energy use. As a result, the pump and fan energy use in IC3 and RUN_30 were distributed into the heating and cooling energy use. The results which simulated with the three programs, RUN_30 (i.e., DOE-2.1e), IC3, and REM/Rate, are summarized in Figure 6. The percent difference for each sector between the programs was:

- For total site energy use, the results between all programs were within 1% difference;
- For lighting and equipment site energy use, the results were the same;
- For space heating, RUN_30 had the heating energy consumption about 5.1% more than IC3 and about 2.8% more than REM/Rate;
- For space cooling, RUN_30 had the cooling energy consumption about 5.1% less than IC3 and about 8.2% less than REM/Rate; and
- For DHW, RUN_30 had no difference against IC3, but about 0.9% less than REM/Rate.



	RUN_30	IC3	REM/Rate
Total	70	70.3	69.4
Area Lights & Equip.	34.3	34.3	34.3
Space Heat	9.46	8.98	9.2
Space Cool	15.44	16.22	16.7
DHW	10.8	10.8	10.9

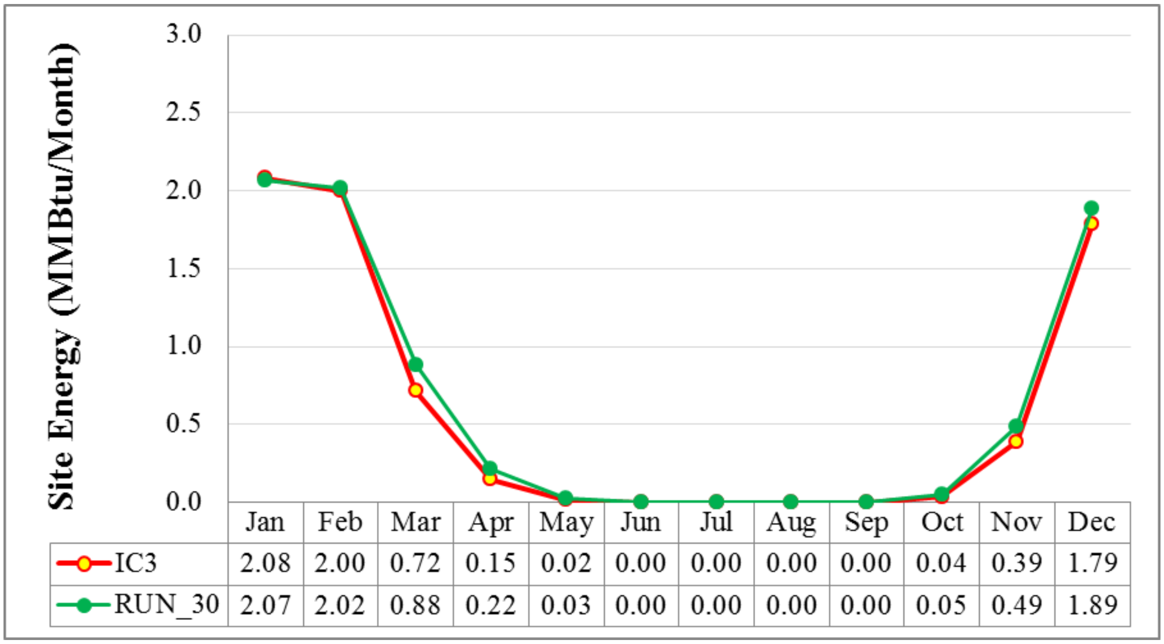
% Energy Use Difference Comparison of RUN_30

		IC3	REM/Rate
Total		0.43%	-0.86%
Area Lights & Equip.		0.00%	0.00%
Space Heat		-5.07%	-2.77%
Space Cool		5.05%	8.17%
DHW		0.00%	0.93%

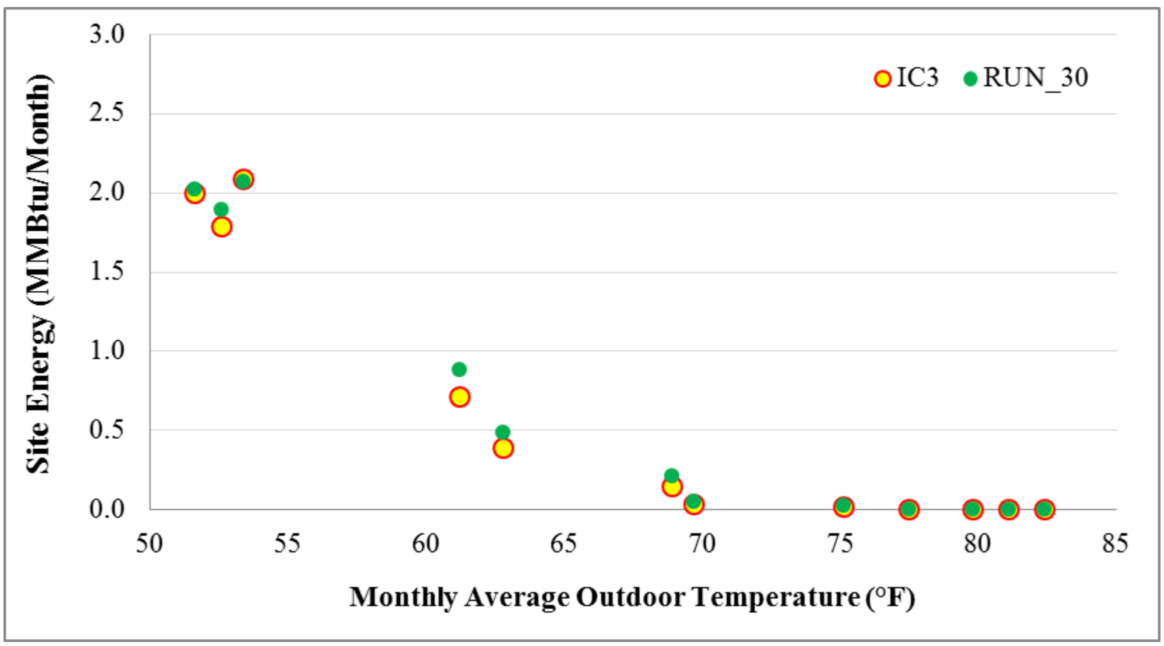
Figure 6: Energy Use Comparison between RUN_30, IC3, and REM/Rate

In addition, the monthly energy use was compared between RUN_30 and IC3[7]. Figure 7 through Figure 10 present the comparison of the monthly energy use by the sectors: heating, cooling, other (i.e., pump, fan, and DHW), and total energy consumption.

[7] REM/Rate was not included for the monthly energy use comparison since REM/Rate does not provide monthly energy use.

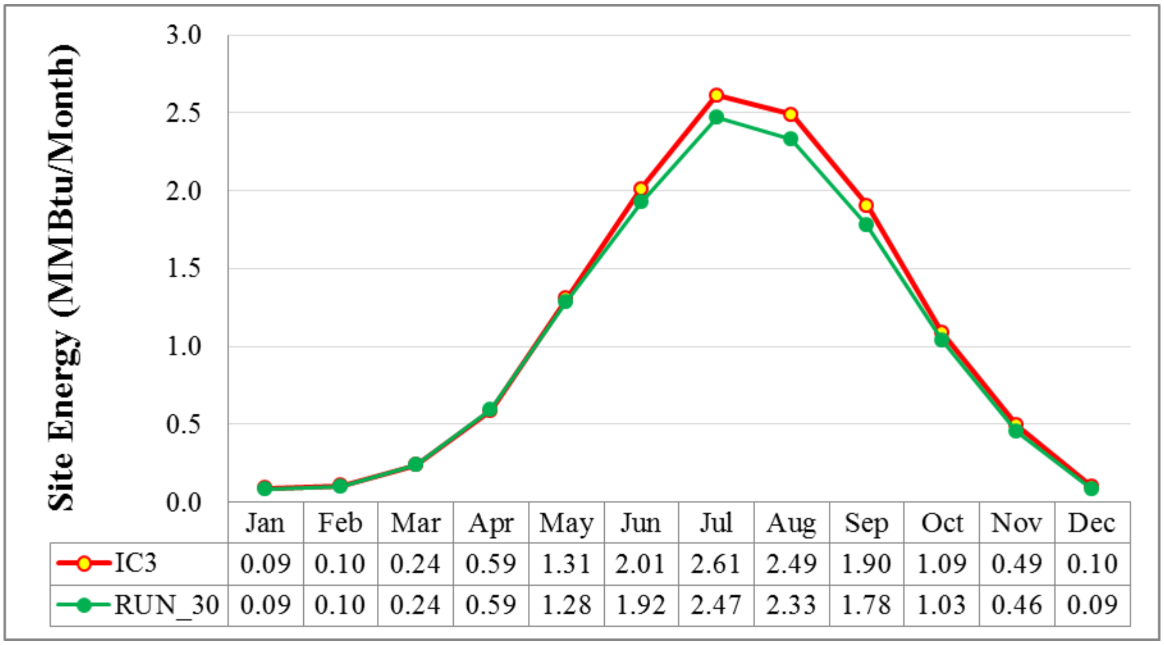


a) Monthly Heating Energy Use

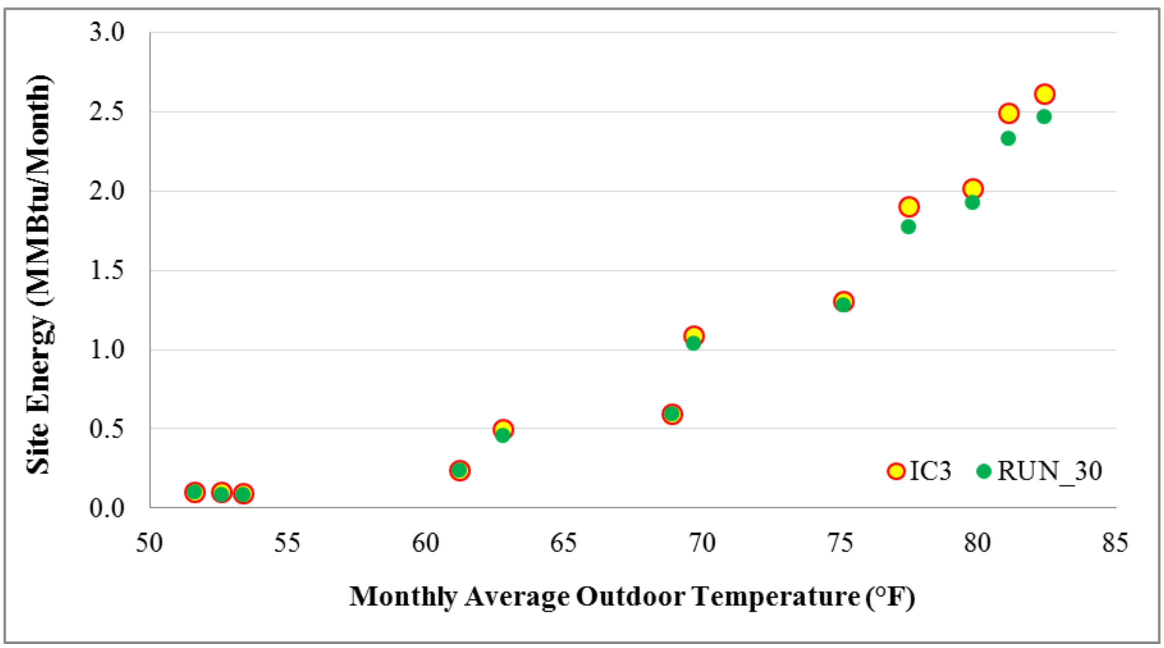


b) Monthly Heating Energy Use Vs. Monthly Average Outdoor Temperature

Figure 7: Monthly Heating Energy Use Comparison between RUN_30 and IC3

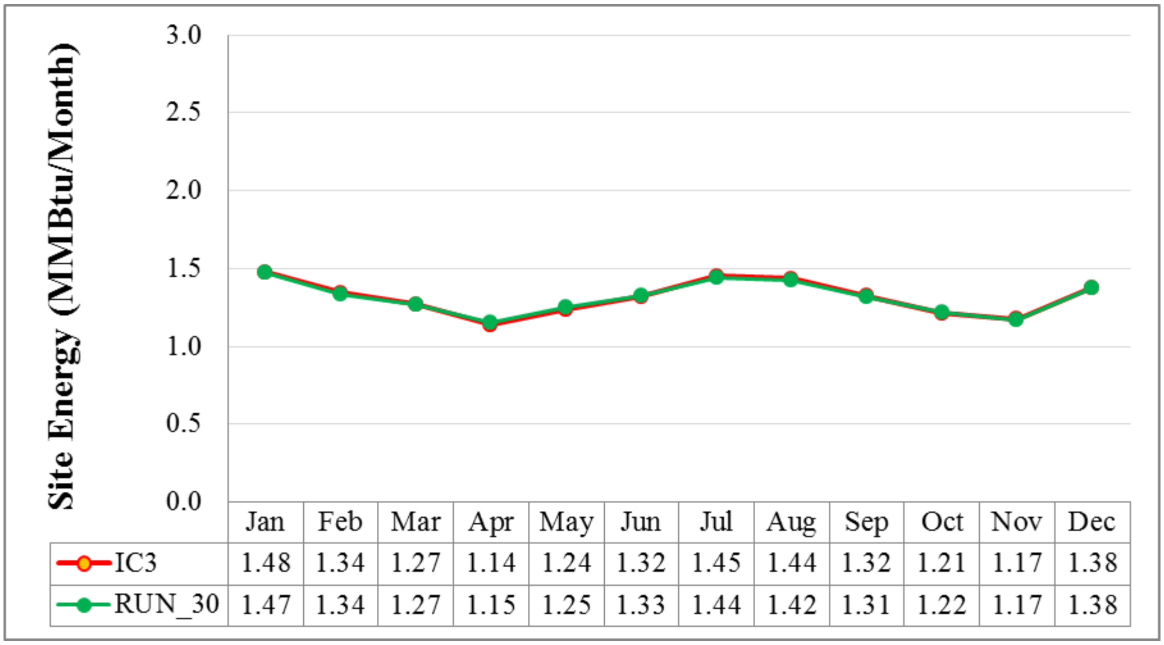


a) Monthly Cooling Energy Use



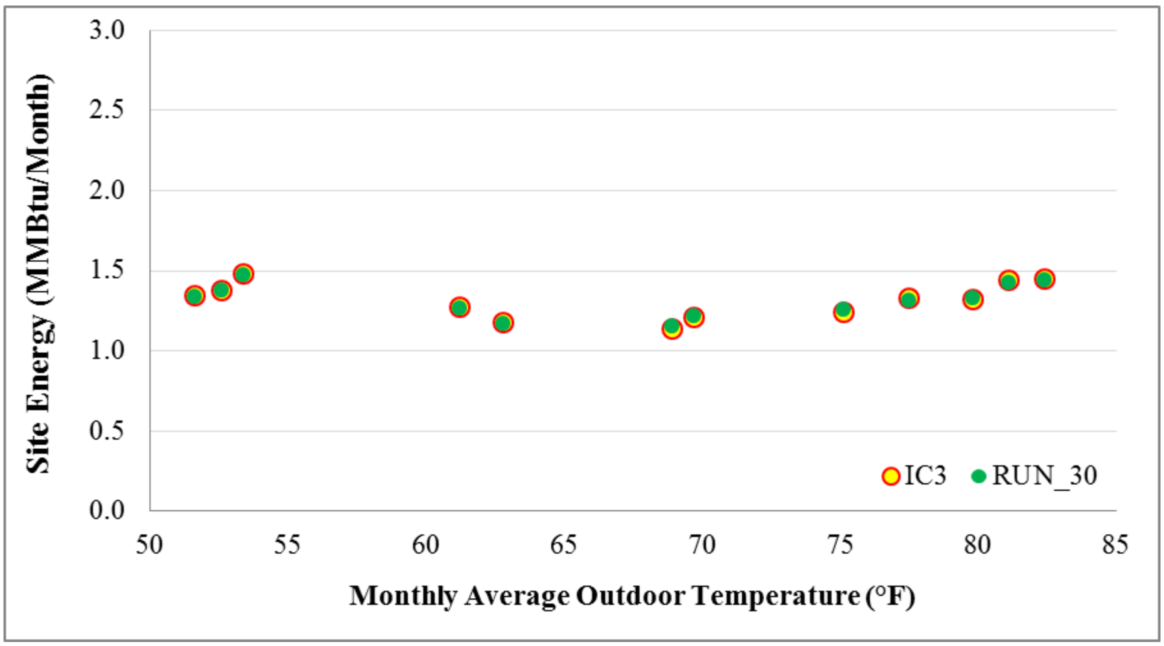
b) Monthly Cooling Energy Use Vs. Monthly Average Outdoor Temperature

Figure 8: Monthly Cooling Energy Use Comparison between RUN_30 and IC3



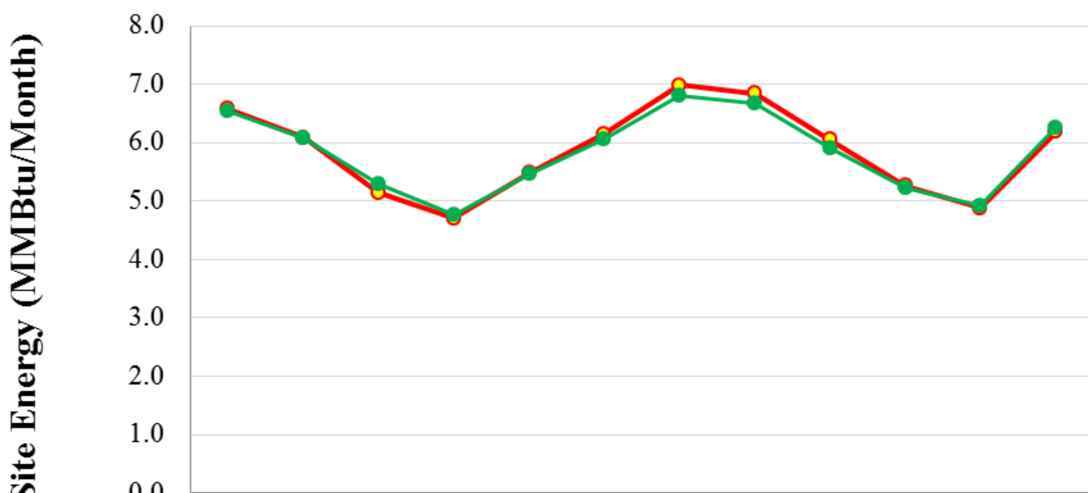
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IC3	1.48	1.34	1.27	1.14	1.24	1.32	1.45	1.44	1.32	1.21	1.17	1.38
RUN_30	1.47	1.34	1.27	1.15	1.25	1.33	1.44	1.42	1.31	1.22	1.17	1.38

a) Monthly Pump, Fan, and DHW Energy Use



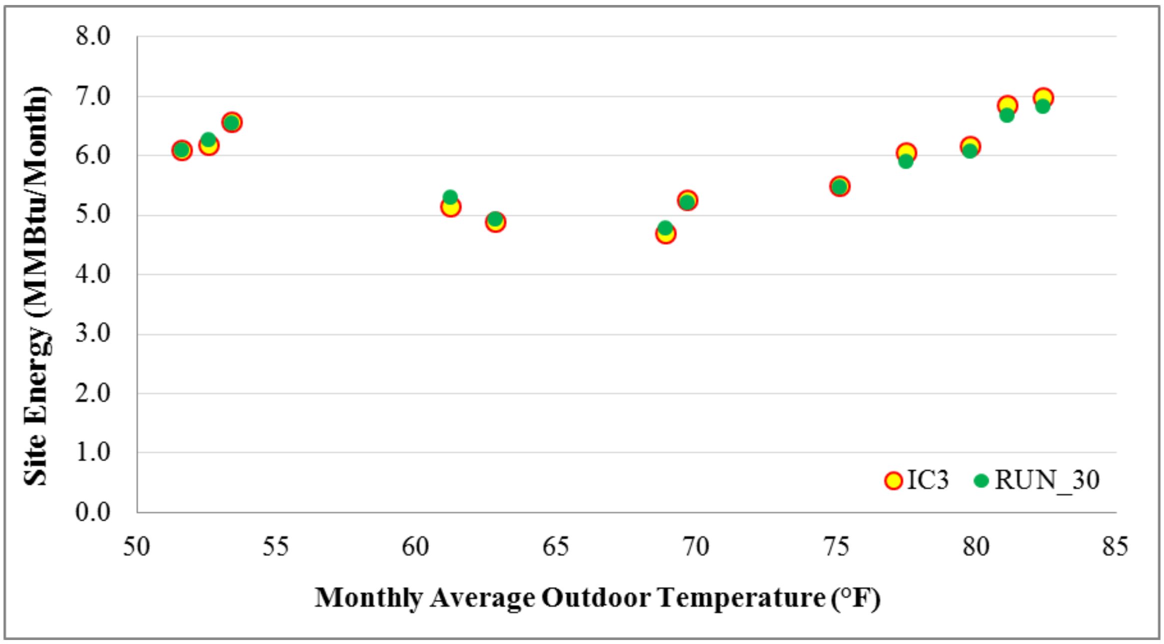
b) Monthly Pump, Fan, and DHW Energy Use Vs. Monthly Average Outdoor Temperature

Figure 9: Monthly Pump, Fan, and DHW Energy Use Comparison between RUN_30 and IC3



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IC3	6.58	6.09	5.15	4.70	5.48	6.16	6.99	6.85	6.05	5.26	4.88	6.18
RUN_30	6.54	6.09	5.29	4.77	5.47	6.07	6.82	6.67	5.90	5.22	4.93	6.26

a) Monthly Total Site Energy Use



b) Monthly Total Site Energy Use Vs. Monthly Average Outdoor Temperature

Figure 10: Monthly Total Site Energy Use Comparison between RUN_30 and IC3

6 Summary

This study was for the DOE-2.1e program to develop a simplified residential ASHP house model in Houston, Texas. The house characteristics were based on the standard reference design and requirements as defined in Chapter 4 of the 2009 IECC.

To develop the 2009 IECC compliant DOE-2.1e residential house model, this study used the step-by-step procedure started from the “RUN 3A” which is one of the examples for a simple structure in the samp1e.inp file included in the DOE-2.1e program package. The RUN 3A is an office building model, which has 30 degrees of azimuth, 5,000 ft^2 of the floor area with 8 feet of the floor-to-ceiling height and 2 feet of the plenum height. Through the step-by-step procedure, the RUN 3A was modified to become a residential model (i.e., RUN_30 in this study), which has a single-story, a single-family, a south-facing and detached house, which has 2,500 ft^2 of the floor area with 8 feet of the floor-to-ceiling height without the plenum. In addition, the residential base-case model replaced with an ASHP system from a VAV system for RUN 3A.

The step-by-step procedure included six categories: *Project* (7 simulation runs), *ASHP System* (7 simulation runs), *Construction* (9 simulation runs), *Internal Gain* (2 simulation runs), *Schedule* (4 simulation runs), and *DHW* (1 simulation run). The *Project* category defined general structures for the simplified residential building model. The *ASHP System* category defined input parameters for the ASHP system. The *Construction* category defined input parameters for the residential building envelope based on the 2009 IECC requirements. The *Internal Gain* category defined input parameters for the energy use of the lighting and equipment. The *Schedule* category defined input parameters for simplified schedules for lighting, equipment, infiltration, and interior shading. Finally, the *DHW* category defined a residential electric DHW system.

The results of the DOE-2.1e code-compliant residential building model, the RUN_30, were compared against the simulation results from other code-compliant simulation programs, which are IC3 and REM/Rate (RESNET, 2013). The results of the total site energy use between all three programs were close, showing the result difference within 1%.

7 References

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Appendices

The appendices present more detailed information of the residential base-case model development procedure and inputs used for the code-compliant simulation programs, including descriptions and screenshots.

The appendices in this study include four sections, as follow:

- Appendix A shows the modification of the input Building Description Language (BDL) file for each step in the procedure to develop the residential base-case model.
- Appendix B shows the input parameter setting for IC3 to compare the simulation result against RUN_30. The input parameters in IC3 include the project information, floors, windows, insulation/mechanical, HVAC/DHW, roof, and horizontal projections.
- Appendix C shows the input parameter setting for REM/Rate version 14.1 to compare simulation results against RUN_30. The inputs in REM/Rate have 12 sections, including site information, building information, slab floors, above-grade walls, windows and glass doors, doors, ceilings, mechanical equipment, ducts systems, infiltration and ventilation, lightings and appliances, and mandatory requirements.
- Appendix D shows the DOE-2.1e BDL input for RUN_30, which is the 2009 IECC code-compliant residential base-case model.

Appendix A: Details of BDL Input File Modification for Each Simulation

This appendix shows the modification of the input Building Description Language (BDL) file for each step to develop the residential base-case model. The procedure to develop the simplified residential base-case model with an ASHP system consists of six categories (30 simulation runs), including categories of the *Project* (7 simulation runs), the *ASHP System* (7 simulation runs), the *Construction* (9 simulation runs), the *Internal Gain* (2 simulation runs), the *Schedule* (4 simulation runs), and the *DHW* (1 simulation run).

The *Project* category defines general structures for the simplified residential building model. The *ASHP System* category defines input parameters for the ASHP system. The *Construction* category defines input parameters for the residential building envelope based on the 2009 IECC requirements. The *Internal Gain* category defines input parameters for the energy use of the lighting and equipment. The *Schedule* category defines input parameters for simplified schedules for lighting, equipment, infiltration, and interior shading. Finally, the *DHW* category defines an electric DHW system.

Table A-1 through Table A-30 include screenshots of the previous input file (i.e., left column in each table) and the post input file (i.e., right column in each table). In addition, the modified BDL inputs were highlighted with a red-lined box. Figure A-1 through Figure A-8 present the plots for the system operation schedule (i.e., heating, cooling, lighting, equipment, fan, and domestic hot water (DHW) heater), infiltration schedule, and interior shading schedule.

A-1. Project category

The *Project* category defines general building structures for the simplified house, such as a number of spaces, area, fenestration, overhang, and orientation.

A-1.1 Modification for RUN_1

This step was to change the number of space from 5 to 1 to simplify the building model.

Table A-1: Modification for RUN_1

RUN_3A	RUN_1
SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE AREA = 1056 VOLUME = 8448 NUMBER-OF-PEOPLE = 11 .. FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 100 X=0 Y=0 Z=0 AZIMUTH = 180 .. WF-1 =WINDOW WIDTH = 45 X = 10 .. DF-1 =DOOR WIDTH = 8 HEIGHT = 8 X = 70 Y = 0 CONSTRUCTION=DOORS OVERHANG-A 1 OVERHANG-B .5 OVERHANG-W 10 OVERHANG-D 4 .. C1-1 =INTERIOR-WALL AREA = 1056 NEXT-TO PLENUM-1 CONSTRUCTION = CLNG-1 .. F1-1 =UNDERGROUND-FLOOR AREA = 1056 CONSTRUCTION = FLOOR-1 .. SB12 =INTERIOR-WALL AREA=135.76 NEXT-TO SPACE2-1 CONSTRUCTION = SB-U .. SB14 =INTERIOR-WALL LIKE SB12 NEXT-TO SPACE4-1 .. SB15 =INTERIOR-WALL AREA 608 NEXT-TO SPACE5-1 CONSTRUCTION = SB-U ..	SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE AREA = 5000 VOLUME = 40000 NUMBER-OF-PEOPLE = 52 .. FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 100 X=0 Y=0 Z=0 AZIMUTH = 180 .. WF-1 =WINDOW WIDTH = 45 X = 10 .. DF-1 =DOOR WIDTH = 8 HEIGHT = 8 X = 70 Y = 0 CONSTRUCTION=DOORS OVERHANG-A 1 OVERHANG-B .5 OVERHANG-W 10 OVERHANG-D 4 .. C1-1 =INTERIOR-WALL AREA = 5000 NEXT-TO PLENUM-1 CONSTRUCTION = CLNG-1 .. F1-1 =UNDERGROUND-FLOOR AREA = 5000 CONSTRUCTION = FLOOR-1 ..
SPACE2-1 =SPACE SPACE-CONDITIONS = OFFICE AREA = 456 VOLUME = 3648 NUMBER-OF-PEOPLE = 5 .. RIGHT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=100 Y=0 Z=0 AZIMUTH = 90 .. WR-1 =WINDOW WIDTH = 25 X = 12.5 .. C2-1 =INTERIOR-WALL AREA = 456 NEXT-TO PLENUM-1 CONSTRUCTION = CLNG-1 .. F2-1 =UNDERGROUND-FLOOR AREA = 456 CONSTRUCTION = CLNG-1 .. SB23 =INTERIOR-WALL AREA = 135.76 NEXT-TO SPACE3-1 CONSTRUCTION = SB-U .. SB25 =INTERIOR-WALL AREA = 208 NEXT-TO SPACE5-1 CONSTRUCTION = SB-U ..	RIGHT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=100 Y=0 Z=0 AZIMUTH = 90 .. WR-1 =WINDOW WIDTH = 25 X = 12.5 ..

```
SPACE3-1          =SPACE                SPACE-CONDITIONS = OFFICE
                                        AREA  = 1056  VOLUME = 8448
                                        NUMBER-OF-PEOPLE = 11   ..

    BACK-1        =EXTERIOR-WALL        HEIGHT = 8  WIDTH = 100
                                        X=100  Y=50  Z=0  AZIMUTH = 0   ..

      WB-1        =WINDOW               WIDTH = 45  X = 10  ..
      DB-1        =DOOR                 WIDTH = 7  HEIGHT = 7
                                        X = 70  Y = 0  CONSTRUCTION=DOORS   ..

    C3-1          =INTERIOR-WALL        AREA = 1056  NEXT-TO PLENUM-1
                                        CONSTRUCTION = CLNG-1   ..

    F3-1          =UNDERGROUND-FLOOR    AREA = 1056
                                        CONSTRUCTION = FLOOR-1   ..

    SB34          =INTERIOR-WALL        AREA = 135.8  NEXT-TO SPACE4-1
                                        CONSTRUCTION = SB-U   ..

    SB35          =INTERIOR-WALL        AREA = 608  NEXT-TO SPACE5-1
                                        CONSTRUCTION = SB-U   ..
```

```
    BACK-1        =EXTERIOR-WALL        HEIGHT = 8  WIDTH = 100
                                        X=100  Y=50  Z=0  AZIMUTH = 0   ..

      WB-1        =WINDOW               WIDTH = 45  X = 10  ..
      DB-1        =DOOR                 WIDTH = 7  HEIGHT = 7
                                        X = 70  Y = 0  CONSTRUCTION=DOORS   ..
```

```
SPACE4-1          =SPACE                SPACE-CONDITIONS = OFFICE
                                        AREA = 456  VOLUME = 3648
                                        NUMBER-OF-PEOPLE = 5   ..

    LEFT-1        =EXTERIOR-WALL        HEIGHT = 8  WIDTH = 50
                                        X=0   Y=50  Z=0   AZIMUTH = 270  ..

      WL-1        =WINDOW               WIDTH = 25  X = 12.5   ..

    C4-1          =INTERIOR-WALL        AREA = 456  NEXT-TO PLENUM-1
                                        CONSTRUCTION = CLNG-1   ..

    F4-1          =UNDERGROUND-FLOOR    AREA = 456
                                        CONSTRUCTION = FLOOR-1   ..

    SB45          =INTERIOR-WALL        AREA = 208  NEXT-TO SPACE5-1
                                        CONSTRUCTION = SB-U   ..
```

```
    LEFT-1        =EXTERIOR-WALL        HEIGHT = 8  WIDTH = 50
                                        X=0   Y=50  Z=0   AZIMUTH = 270  ..

      WL-1        =WINDOW               WIDTH = 25  X = 12.5   ..
```

```
SPACE5-1          =SPACE                SPACE-CONDITIONS = OFFICE
                                        AREA = 1976  VOLUME = 15808
                                        NUMBER-OF-PEOPLE = 20   ..

    C5-1          =INTERIOR-WALL        AREA = 1976  NEXT-TO PLENUM-1
                                        CONSTRUCTION = CLNG-1   ..

    F5-1          =UNDERGROUND-FLOOR    AREA = 1976  CONSTRUCTION = FLOOR-1 ..
```

Removed

A-1.3 Modification for RUN_2

This step was to decrease the building area from 50,00ft^2 to 2,500 ft^2 for a typical single-family house. The building foot print was also changed from a right rectangular to a perfect square. According to the reduced the building area, the Window-to-Floor Ratio (WFR) and the door area were reduced from 22% to 15% and from 113 ft^2 to 40 ft^2, based on Table 405.5.2(1) in 2009 IECC.

Table A-2: Modification for RUN_2

RUN_1	RUN_2
PLENUM-1 =SPACE ZONE-TYPE=PLENUM AREA=5000 VOLUME=10000 Z=8 FLOOR-WEIGHT=5 .. WALL-1PF =EXTERIOR-WALL HEIGHT = 2 WIDTH = 100 AZIMUTH = 180 .. WALL-1PR =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50 AZIMUTH = 90 X = 100 .. WALL-1PB =EXTERIOR-WALL HEIGHT = 2 WIDTH = 100 X = 100 Y = 50 AZIMUTH = 0 .. WALL-1PL =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50 AZIMUTH = 270 Y = 50 .. TOP-1 =ROOF HEIGHT=50 WIDTH=100 X=0 Y=0 Z=2 AZIMUTH = 180 TILT=0 GND-REFLECTANCE=0 CONSTRUCTION = ROOF-1 ..	PLENUM-1 =SPACE ZONE-TYPE=PLENUM AREA=2500 VOLUME=5000 Z=8 FLOOR-WEIGHT=5 .. WALL-1PF =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50 AZIMUTH = 180 .. WALL-1PR =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50 AZIMUTH = 90 X = 50 .. WALL-1PB =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50 X = 50 Y = 50 AZIMUTH = 0 .. WALL-1PL =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50 AZIMUTH = 270 Y = 50 .. TOP-1 =ROOF HEIGHT=50 WIDTH=50 X=0 Y=0 Z=2 AZIMUTH = 180 TILT=0 GND-REFLECTANCE=0 CONSTRUCTION = ROOF-1 ..
SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE AREA = 5000 VOLUME = 40000 NUMBER-OF-PEOPLE = 52 .. FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 100 X=0 Y=0 Z=0 AZIMUTH = 180 .. WF-1 =WINDOW WIDTH = 45 X = 10 .. DF-1 =DOOR WIDTH = 8 HEIGHT = 8 X = 70 Y = 0 CONSTRUCTION=DOORS OVERHANG-A 1 OVERHANG-B .5 OVERHANG-W 10 OVERHANG-D 4 .. C1-1 =INTERIOR-WALL AREA = 5000 NEXT-TO PLENUM-1 CONSTRUCTION = CLNG-1 .. F1-1 =UNDERGROUND-FLOOR AREA = 5000 CONSTRUCTION = FLOOR-1 ..	SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE AREA = 2500 VOLUME = 20000 NUMBER-OF-PEOPLE = 52 .. FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=0 Y=0 Z=0 AZIMUTH = 180 .. WF-1 =WINDOW WIDTH = 18.75 X = 15.625 .. DF-1 =DOOR WIDTH = 3 HEIGHT = 6.67 X = 41 Y = 0 CONSTRUCTION=DOORS OVERHANG-A 1 OVERHANG-B .5 OVERHANG-W 10 OVERHANG-D 4 .. C1-1 =INTERIOR-WALL AREA = 2500 NEXT-TO PLENUM-1 CONSTRUCTION = CLNG-1 .. F1-1 =UNDERGROUND-FLOOR AREA = 2500 CONSTRUCTION = FLOOR-1 ..

RIGHT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=100 Y=0 Z=0 AZIMUTH = 90 .. WR-1 =WINDOW WIDTH = 25 X = 12.5 ..	RIGHT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=50 Y=0 Z=0 AZIMUTH = 90 .. WR-1 =WINDOW WIDTH = 18.75 X = 15.625 ..
BACK-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 100 X=100 Y=50 Z=0 AZIMUTH = 0 .. WB-1 =WINDOW WIDTH = 45 X = 10 .. DB-1 =DOOR WIDTH = 7 HEIGHT = 7 X = 70 Y = 0 CONSTRUCTION=DOORS ..	BACK-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=50 Y=50 Z=0 AZIMUTH = 0 .. WB-1 =WINDOW WIDTH = 18.75 X = 15.625 .. DF-2 =DOOR WIDTH = 3 HEIGHT = 6.67 X = 41 Y = 0 CONSTRUCTION=DOORS ..
LEFT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=0 Y=50 Z=0 AZIMUTH = 270 .. WL-1 =WINDOW WIDTH = 25 X = 12.5 ..	LEFT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=0 Y=50 Z=0 AZIMUTH = 270 .. WL-1 =WINDOW WIDTH = 18.75 X = 15.625 ..

A-1.4 Modification for RUN_3

The simulation RUN_3 removed the overhang on the south door.

Table A-3: Modification for RUN_3

RUN_2	RUN_3
SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE AREA = 2500 VOLUME = 20000 NUMBER-OF-PEOPLE = 52 .. FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=0 Y=0 Z=0 AZIMUTH = 180 .. WF-1 =WINDOW WIDTH = 18.75 X = 15.625 .. DF-1 =DOOR WIDTH = 3 HEIGHT = 6.67 X = 41 Y = 0 CONSTRUCTION=DOORS OVERHANG-A 1 OVERHANG-B .5 OVERHANG-W 10 OVERHANG-D 4 ..	SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE AREA = 2500 VOLUME = 20000 NUMBER-OF-PEOPLE = 52 .. FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=0 Y=0 Z=0 AZIMUTH = 180 .. WF-1 =WINDOW WIDTH = 18.75 X = 15.625 .. DF-1 =DOOR WIDTH = 3 HEIGHT = 6.67 X = 41 Y = 0 CONSTRUCTION=DOORS ..

A-1.5 Modification for RUN_4

The simulation RUN_4 rotated the building orientation facing to the South

Table A-4: Modification for RUN_4

RUN_3	RUN_4
RUN-PERIOD JAN 1 2012 THRU DEC 31 2012 ..	RUN-PERIOD JAN 1 2012 THRU DEC 31 2012 ..
ABORT ERRORS ..	ABORT ERRORS ..
DIAGNOSTIC WARNINGS ..	DIAGNOSTIC WARNINGS ..
LOADS-REPORT SUMMARY = (ALL-SUMMARY)	LOADS-REPORT SUMMARY = (ALL-SUMMARY)
VERIFICATION = (ALL-VERIFICATION) ..	VERIFICATION = (ALL-VERIFICATION) ..
BUILDING-LOCATION LATITUDE=30 LONGITUDE=95.4	BUILDING-LOCATION LATITUDE=30 LONGITUDE=95.4
ALTITUDE=108	ALTITUDE=108
TIME-ZONE=6 AZIMUTH=30 ..	TIME-ZONE=6 AZIMUTH=0 ..

A-1.6 Modification for RUN_5

The simulation RUN_5 sets the number of occupancy from 52 to 0.

Table A-5: Modification for RUN_5

RUN_4	RUN_5
SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE	SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE
AREA = 2500 VOLUME = 20000	AREA = 2500 VOLUME = 20000
NUMBER-OF-PEOPLE = 52 ..	NUMBER-OF-PEOPLE = 0 ..

A-1.7 Modification for RUN_6

The simulation RUN_6 removed the plenum for the residential model to be simplified. Absence of plenum space changes the return air path input from plenum to direct.

Table A-6: Modification for RUN_6

RUN_5	RUN_6
PLENUM-1 =SPACE ZONE-TYPE=PLENUM AREA=2500	
VOLUME=5000 Z=8 FLOOR-WEIGHT=5 ..	
WALL-1PF =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50	
AZIMUTH = 180 ..	
WALL-1PR =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50	
AZIMUTH = 90 X = 50 ..	
WALL-1PB =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50	
X = 50 Y = 50 AZIMUTH = 0 ..	
WALL-1PL =EXTERIOR-WALL HEIGHT = 2 WIDTH = 50	
AZIMUTH = 270 Y = 50 ..	SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE
	AREA = 2500 VOLUME = 20000
TOP-1 =ROOF HEIGHT=50 WIDTH=50	NUMBER-OF-PEOPLE = 4 ..
X=0 Y=0 Z=2 AZIMUTH = 180	
TILT=0 GND-REFLECTANCE=0	TOP-1 =ROOF HEIGHT=50 WIDTH=50
CONSTRUCTION = ROOF-1 ..	X=0 Y=0 Z=8 AZIMUTH = 180
	TILT=0 GND-REFLECTANCE=0
SPACE1-1 =SPACE SPACE-CONDITIONS = OFFICE	CONSTRUCTION = ROOF-1 ..
AREA = 2500 VOLUME = 20000	
NUMBER-OF-PEOPLE = 4 ..	
FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50	FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50
X=0 Y=0 Z=0 AZIMUTH = 180 ..	X=0 Y=0 Z=0 AZIMUTH = 180 ..
WF-1 =WINDOW WIDTH = 18.75 X = 15.625 ..	WF-1 =WINDOW WIDTH = 18.75 X = 15.625 ..
DF-1 =DOOR WIDTH = 3 HEIGHT = 6.67	DF-1 =DOOR WIDTH = 3 HEIGHT = 6.67
X = 41 Y = 0 CONSTRUCTION=DOORS ..	X = 41 Y = 0 CONSTRUCTION=DOORS ..
C1-1 =INTERIOR-WALL AREA = 2500 NEXT-TO PLENUM-1	
CONSTRUCTION = CLNG-1 ..	
F1-1 =UNDERGROUND-FLOOR AREA = 2500 CONSTRUCTION = FLOOR-1 ..	F1-1 =UNDERGROUND-FLOOR AREA = 2500 CONSTRUCTION = FLOOR-1 ..

SPACE1-1 =ZONE ZONE-AIR=ZAIR SIZING-OPTION=ADJUST-LOADS	SPACE1-1 =ZONE ZONE-AIR=ZAIR SIZING-OPTION=ADJUST-LOADS
ZONE-CONTROL=CONTROL ASSIGNED-CFM=7366 ..	ZONE-CONTROL=CONTROL ASSIGNED-CFM=7366 ..
PLENUM-1 =ZONE ZONE-TYPE=PLENUM SIZING-OPTION=ADJUST-LOADS	
DESIGN-HEAT-T=50 DESIGN-COOL-T=95 ..	
SYST-1 =SYSTEM SYSTEM-TYPE=VAVS	SYST-1 =SYSTEM SYSTEM-TYPE=VAVS
SUPPLY-CFM=7366	SUPPLY-CFM=7366
SYSTEM-CONTROL= S-CONT	SYSTEM-CONTROL= S-CONT
SYSTEM-FANS= S-FAN	SYSTEM-FANS= S-FAN
SYSTEM-TERMINAL= S-TERM	SYSTEM-TERMINAL= S-TERM
ECONO-LIMIT-T=65	ECONO-LIMIT-T=65
RETURN-AIR-PATH=PLENUM-ZONES	RETURN-AIR-PATH= DIRECT
PLENUM-NAMES=(PLENUM-1)	ZONE-NAMES=(SPACE1-1) ..
ZONE-NAMES=(SPACE1-1,PLENUM-1) ..	

A-1.8 Modification for RUN_7

The simulation RUN_7 modified the door size and the location, from two doors (on the south wall and the north wall) to a single door (on the north wall only), based on Table 405.5.2(1) in 2009 IEC.

Table A-7: Modification for RUN_7

RUN_6	RUN_7
FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50	FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50
X=0 Y=0 Z=0 AZIMUTH = 180 ..	X=0 Y=0 Z=0 AZIMUTH = 180 ..
WF-1 =WINDOW WIDTH = 18.75 X = 15.625 ..	WF-1 =WINDOW WIDTH = 18.75 X = 15.625 ..
DF-1 =DOOR WIDTH = 3 HEIGHT = 6.67	
X = 41 Y = 0 CONSTRUCTION=DOORS ..	
BACK-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50	BACK-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50
X=50 Y=50 Z=0 AZIMUTH = 0 ..	X=50 Y=50 Z=0 AZIMUTH = 0 ..
WB-1 =WINDOW WIDTH = 18.75 X = 15.625 ..	WB-1 =WINDOW WIDTH = 18.75 X = 15.625 ..
DF-2 =WINDOW WIDTH = 3 HEIGHT = 6.67	DF-1 =DOOR WIDTH = 6 HEIGHT = 6.67
X = 41 Y = 0 GLASS-TYPE=DOORS ..	X = 41 Y = 0 CONSTRUCTION=DOORS ..

A-2. ASHP system category

The *ASHP System* category defines input parameters, such as system efficiency and thermostat setting, for the Air-Source Heat Pump (ASHP) system model from the Variable Air Volume system (VAVS) used in RUN_3A. The ASHP system can be modeled with Residential system type, which is RESYS in the DOE-2.1e program.

A-2.1 Modification for RUN_8

In the simulation RUN_8, the HVAC system was changed from VAVS system to residential system (i.e., RESYS in DOE-2.1e) with Air-Source Heat Pump (ASHP). The input modification from VAVS to RESYS is explained, as below:

- Input for COOLING/HEATING SCHEDULE[8], DAY-RESET-SCH[9], ECONO-LIMIT-T[10], SYSTEM-TERMINAL, Variable Frequency Drive (VFD) Fan (i.e., FAN-CONTROL = SPEED), and PLANT are not suitable/available for the residential system
- The proportional thermostat with 2°F throttling range, which is DEO-2 default, was used for the RESYS system
- VENT-METHOD was added into the RESYS system to introduce outdoor air
- SYSTEM-CAPACITY was determined as 60,000 Btu/hr for both heating and cooling, using the rule of thumb, which is 500 ft^2/ton and 1,200 Btu/hr-ton.

[8] This command in “ZONE-CONTROL” instruction represents available cooling/heating time period depends on ambient temperature.
[9] This command in “RESET-SCHEDULE” instruction represents relationship between outdoor temperature and system output with system supply temperature and outdoor temperature.
[10] This command in “SYSTEM-CONTROL” instruction decides return air temperature.

Table A-8: Modification for RUN_8

RUN_7	RUN_8
$ SYSTEMS SCHEDULES FAN-1 =DAY-SCHEDULE (1,6)(0)(7,8)(-999)(9,18)(1)(19,24)(0) . FAN-2 =DAY-SCHEDULE (1,24) (0) .. FAN-SCHED =SCHEDULE THRU DEC 31 (WD) FAN-1 (WEH) FAN-2 .. HEAT-1 =DAY-SCHEDULE (1,8) (55) (9,18) (70) (19,24) (55) .. HEAT-2 =DAY-SCHEDULE (1,24) (55) .. HEAT-WEEK =WEEK-SCHEDULE (MON,FRI) HEAT-1 (WEH) HEAT-2 .. HEAT-SCHED =SCHEDULE THRU DEC 31 HEAT-WEEK .. COOLOFF =SCHEDULE THRU DEC 31 (ALL) (1,24) (60) .. HEATOFF =SCHEDULE THRU DEC 31 (ALL) (1,24) (60) .. COOL-1 =DAY-SCHEDULE (1,8) (99) (9,18) (78) (19,24) (99) .. COOL-2 =DAY-SCHEDULE (1,24) (99) .. COOL-WEEK =WEEK-SCHEDULE (MON,FRI) COOL-1 (WEH) COOL-2 .. COOL-SCHED =SCHEDULE THRU DEC 31 COOL-WEEK .. R1 =DAY-RESET-SCH SUPPLY-HI=60 SUPPLY-LO=52 OUTSIDE-LO=30 OUTSIDE-HI=75 .. SAT-RESET =RESET-SCHEDULE THRU DEC 31 (ALL) R1 ..	$ SYSTEMS SCHEDULES FAN-1 =DAY-SCHEDULE (1,6)(0)(7,8)(-999)(9,18)(1)(19,24)(0) FAN-2 =DAY-SCHEDULE (1,24) (0) .. FAN-SCHED =SCHEDULE THRU DEC 31 (WD) FAN-1 (WEH) FAN-2 .. HEAT-1 =DAY-SCHEDULE (1,8) (55) (9,18) (70) (19,24) (55) .. HEAT-2 =DAY-SCHEDULE (1,24) (55) .. HEAT-WEEK =WEEK-SCHEDULE (MON,FRI) HEAT-1 (WEH) HEAT-2 .. HEAT-SCHED =SCHEDULE THRU DEC 31 HEAT-WEEK .. COOL-1 =DAY-SCHEDULE (1,8) (99) (9,18) (78) (19,24) (99) .. COOL-2 =DAY-SCHEDULE (1,24) (99) .. COOL-WEEK =WEEK-SCHEDULE (MON,FRI) COOL-1 (WEH) COOL-2 .. COOL-SCHED =SCHEDULE THRU DEC 31 COOL-WEEK ..
CONTROL =ZONE-CONTROL DESIGN-HEAT-T=70 DESIGN-COOL-T=76 HEAT-TEMP-SCH= HEAT-SCHED COOL-TEMP-SCH= COOL-SCHED THERMOSTAT-TYPE=REVERSE-ACTION ..	CONTROL =ZONE-CONTROL DESIGN-HEAT-T=70 DESIGN-COOL-T=76 HEAT-TEMP-SCH= HEAT-SCHED COOL-TEMP-SCH= COOL-SCHED THERMOSTAT-TYPE=PROPORTIONAL THROTTLING-RANGE = 2 ..

```
S-CONT        =SYSTEM-CONTROL  COOLING-SCHEDULE= COOLOFF
                               HEATING-SCHEDULE= HEATOFF
                               HEAT-SET-T=65
                               COOL-CONTROL=RESET
                               COOL-RESET-SCH=SAT-RESET
                               MIN-SUPPLY-T=60 ..

S-FAN         =SYSTEM-FANS     FAN-SCHEDULE=FAN-SCHED  FAN-CONTROL=SPEED
                               SUPPLY-STATIC=5.5  SUPPLY-EFF=.55
                               NIGHT-CYCLE-CTRL=CYCLE-ON-ANY  ..

S-TERM        =SYSTEM-TERMINAL REHEAT-DELTA-T=58
                               MIN-CFM-RATIO=0.3    ..

SYST-1        =SYSTEM          SYSTEM-TYPE=VAVS
                               SUPPLY-CFM=7366
                               SYSTEM-CONTROL= S-CONT
                               SYSTEM-FANS= S-FAN
                               SYSTEM-TERMINAL= S-TERM
                               ECONO-LIMIT-T=65
                               RETURN-AIR-PATH= DIRECT
                               ZONE-NAMES=(SPACE1-1)    ..



END   ..
```

```
S-CONT        =SYSTEM-CONTROL   MIN-SUPPLY-T=55  ..


S-AIR         =SYSTEM-AIR       VENT-METHOD = AIR-CHANGE  ..



S-FAN         =SYSTEM-FANS      FAN-SCHEDULE=FAN-SCHED  FAN-CONTROL=CYCLING
                                SUPPLY-DELTA-T = 1.57826  SUPPLY-KW= 0.00051



SYST-1        =SYSTEM           SYSTEM-TYPE=RESYS
                                SUPPLY-CFM=7366
                                SYSTEM-CONTROL= S-CONT
                                SYSTEM-FANS= S-FAN
                                ZONE-NAMES=(SPACE1-1)
                                SYSTEM-AIR = S-AIR
                                HEAT-SOURCE= HEAT-PUMP
                                COOLING-CAPACITY = 60000
                                HEATING-CAPACITY = -60000
                                HP-SUPP-SOURCE= ELECTRIC    ..

HP-1          =PLANT-ASSIGNMENT
                                SYSTEM-NAMES=(SYST-1)
                                HP-LOOP-HEATING= FROM-SYSTEMS
                                HP-LOOP-COOLING= FROM-SYSTEMS    ..




END   ..
```

```
INPUT PLANT    ..

              PLANT-REPORT  SUMMARY=(PS-A,BEPS)  ..

                $ EQUIPMENT DESCRIPTION

                $ HOT-WATER BOILER

SBOIL1   =PLANT-EQUIPMENT  TYPE=HW-BOILER  SIZE=.457  .. $ SIZE FROM RUN 3

          PLANT-PARAMETERS  HERM-REC-COND-TYPE=AIR  ..

                $ AIR-COOLED RECIPROCATING CHILLER

CHIL1    =PLANT-EQUIPMENT  TYPE=HERM-REC-CHLR  SIZE=.222  .. $ SIZE FROM R

 PLANT-COSTS       PROJECT-LIFE=25  DISCOUNT-RATE=5 ..
 ENERGY-RESOURCE   RESOURCE=ELECTRICITY  ..
 ENERGY-RESOURCE   RESOURCE=NATURAL-GAS  ENERGY/UNIT=100000
                   UNIT-NAME=THERMS    ..
END  ..
```

```
INPUT PLANT    ..

              PLANT-REPORT  SUMMARY=(ALL-SUMMARY)  ..

                $ EQUIPMENT DESCRIPTION

                $ HOT-WATER BOILER

$ SIZE FROM RUN 3



                $ AIR-COOLED RECIPROCATING CHILLER

 $ SIZE FROM RUN 3

 PLANT-COSTS       PROJECT-LIFE=25  DISCOUNT-RATE=5 ..
 ENERGY-RESOURCE   RESOURCE=ELECTRICITY  ..
 ENERGY-RESOURCE   RESOURCE=NATURAL-GAS  ENERGY/UNIT=100000
                   UNIT-NAME=THERMS    ..
END  ..
```

A-2.2 Modification for RUN_9 & RUN_10

Based on Table 503.2.3(1) and Table 503.2.3(2) in the IECC 2009, the cooling system efficiency was changed from SEER 7.3 to SEER 13, and the heating system efficiency was changed from HSPF 5.4 to HSPF 7.7. The equivalent cooling Energy Input Ratio (EIR) for SEER 13 is 0.211695 and heating EIR for HSPF 7.7 is 0.230611, which was described in section 3.2.

Table A-9: Modification for RUN_9

RUN_8	RUN_9
SYST-1 =SYSTEM SYSTEM-TYPE=RESYS	SYST-1 =SYSTEM SYSTEM-TYPE=RESYS
SUPPLY-CFM=7366	SUPPLY-CFM=7366
SYSTEM-CONTROL= S-CONT	SYSTEM-CONTROL= S-CONT
SYSTEM-FANS= S-FAN	SYSTEM-FANS= S-FAN COOLING-EIR = 0.211695
ZONE-NAMES=(SPACE1-1)	ZONE-NAMES=(SPACE1-1)
SYSTEM-AIR = S-AIR	SYSTEM-AIR = S-AIR
HEAT-SOURCE= HEAT-PUMP	HEAT-SOURCE= HEAT-PUMP
COOLING-CAPACITY = 60000	COOLING-CAPACITY = 60000
HEATING-CAPACITY = -60000	HEATING-CAPACITY = -60000
HP-SUPP-SOURCE= ELECTRIC ..	HP-SUPP-SOURCE= ELECTRIC ..

Table A-10: Modification for RUN_10

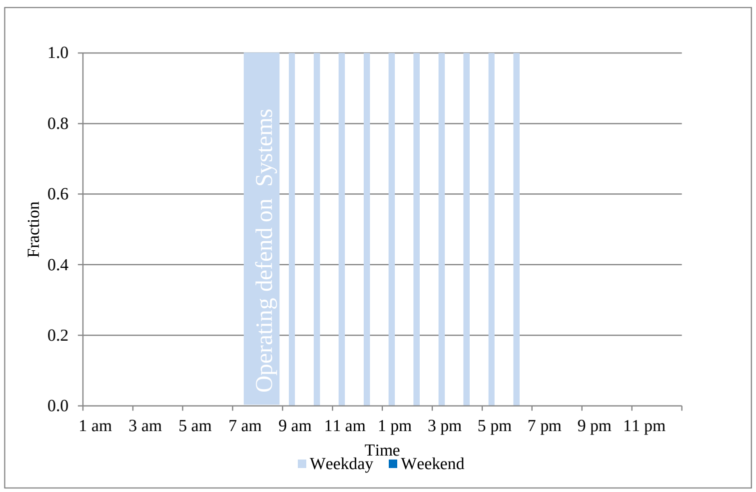
RUN_9	RUN_10
SYST-1 =SYSTEM SYSTEM-TYPE=RESYS	SYST-1 =SYSTEM SYSTEM-TYPE=RESYS
SUPPLY-CFM=7366	SUPPLY-CFM=7366
SYSTEM-CONTROL= S-CONT	SYSTEM-CONTROL= S-CONT
SYSTEM-FANS= S-FAN COOLING-EIR = 0.211695	SYSTEM-FANS= S-FAN COOLING-EIR = 0.211695
ZONE-NAMES=(SPACE1-1)	ZONE-NAMES=(SPACE1-1) HEATING-EIR = 0.236011
SYSTEM-AIR = S-AIR	SYSTEM-AIR = S-AIR
HEAT-SOURCE= HEAT-PUMP	HEAT-SOURCE= HEAT-PUMP
COOLING-CAPACITY = 60000	COOLING-CAPACITY = 60000
HEATING-CAPACITY = -60000	HEATING-CAPACITY = -60000
HP-SUPP-SOURCE= ELECTRIC ..	HP-SUPP-SOURCE= ELECTRIC ..

A-2.3 Modification for RUN_11

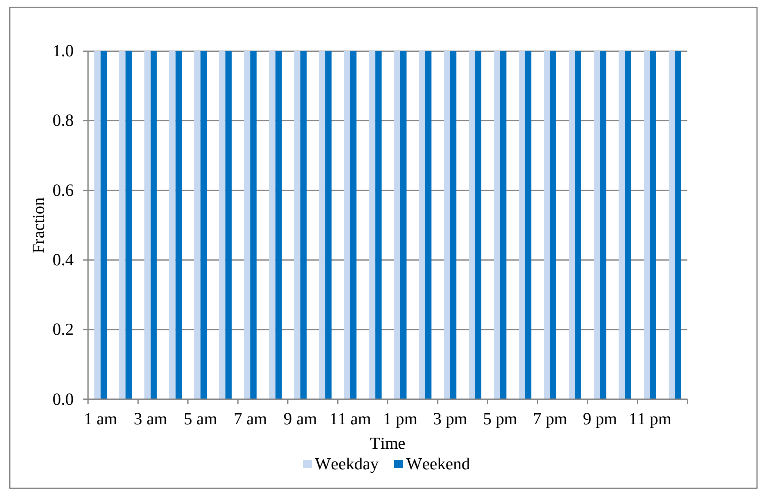
The simulation RUN_11 modified the system fans to always run . The fan operating schedule is shown in Figure A-1.

Table A-11: Modification for RUN_11

RUN_10	RUN_11
235 $ SYSTEMS SCHEDULES 236 237 FAN-1 =DAY-SCHEDULE (1,6) (0) (7,8) (-999) (9,18) (1) (19,24) (0) 238 FAN-2 =DAY-SCHEDULE (1,24) (0) .. 239 FAN-SCHED =SCHEDULE THRU DEC 31 (WD) FAN-1 (WEH) FAN-2 ..	235 $ SYSTEMS SCHEDULES 236 237 FAN-1 =DAY-SCHEDULE (1,24) (1) .. 238 FAN-2 =DAY-SCHEDULE (1,24) (1) .. 239 FAN-SCHED =SCHEDULE THRU DEC 31 (WD) FAN-1 (WEH) FAN-2 ..



RUN_10



RUN_11

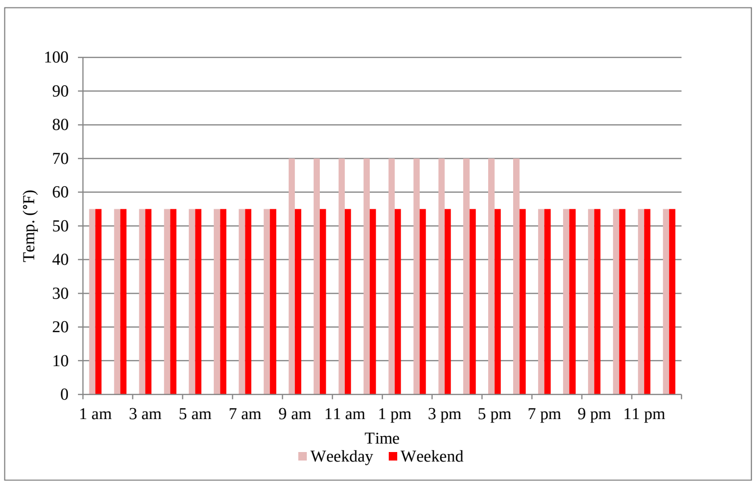
Figure A-1: Fan Operating Schedules for RUN_10 and RUN_11

A-2.4 Modification for RUN_12 & 13

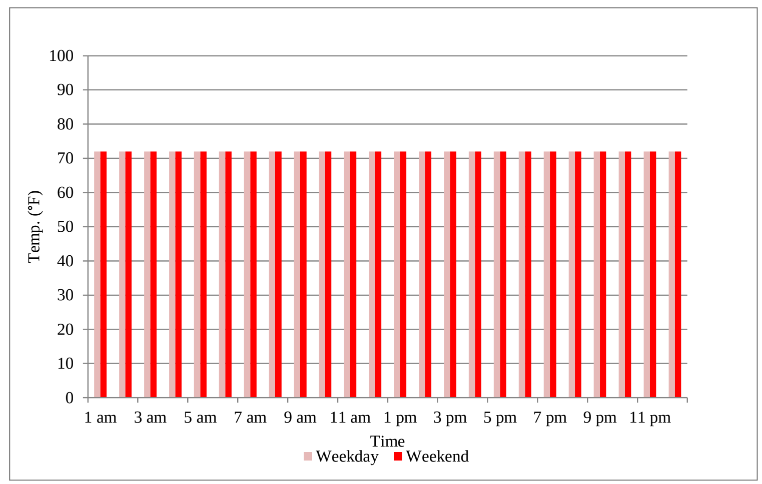
Based on Table 405.5.2(1) in the 2009 IECC, heating and cooling thermostat temperatures were set constantly to 75°F for cooling and 72°F for heating. The heating and cooling schedules are shown in Figure A-2 and Figure A-3, respectively.

Table A-12: Modification for RUN_12

RUN_11	RUN_12
`HEAT-1 =DAY-SCHEDULE (1,8) (55) (9,18) (70) (19,24) (55) ..`	`HEAT-1 =DAY-SCHEDULE (1,24) (72) ..`
`HEAT-2 =DAY-SCHEDULE (1,24) (55) ..`	`HEAT-2 =DAY-SCHEDULE (1,24) (72) ..`
`HEAT-WEEK =WEEK-SCHEDULE (MON,FRI) HEAT-1 (WEH) HEAT-2 ..`	`HEAT-WEEK =WEEK-SCHEDULE (MON,FRI) HEAT-1 (WEH) HEAT-2 ..`
`HEAT-SCHED =SCHEDULE THRU DEC 31 HEAT-WEEK ..`	`HEAT-SCHED =SCHEDULE THRU DEC 31 HEAT-WEEK ..`



RUN_11



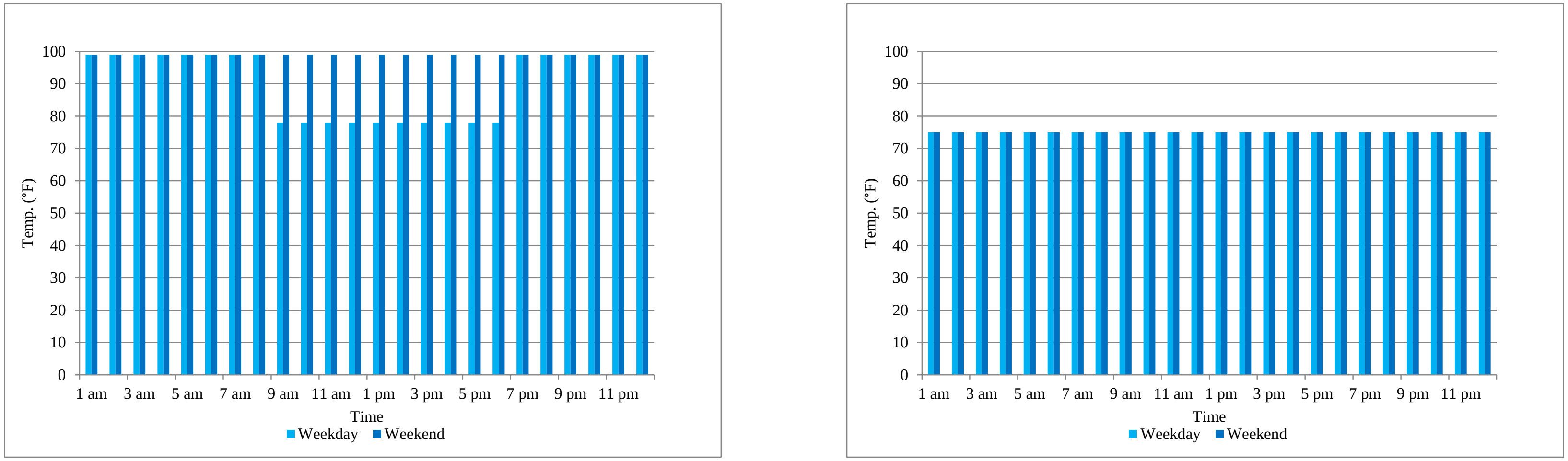
RUN_12

Figure A-2: Heating Schedules for RUN_11 and RUN_12

Table A-13: Modification for RUN_13

RUN_12	RUN_13

`COOL-1 =DAY-SCHEDULE (1,8) (99) (9,18) (78) (19,24) (99) ..`
`COOL-2 =DAY-SCHEDULE (1,24) (99) ..`
`COOL-WEEK =WEEK-SCHEDULE (MON,FRI) COOL-1 (WEH) COOL-2 ..`
`COOL-SCHED =SCHEDULE THRU DEC 31 COOL-WEEK ..`
	`COOL-1 =DAY-SCHEDULE (1,24) (75) ..`
	`COOL-2 =DAY-SCHEDULE (1,24) (75) ..`
	`COOL-WEEK =WEEK-SCHEDULE (MON,FRI) COOL-1 (WEH) COOL-2 ..`
	`COOL-SCHED =SCHEDULE THRU DEC 31 COOL-WEEK ..`



RUN_12 RUN_13

Figure A-3: Cooling Schedules for RUN_12 and RUN_13

A-2.5 Modification for RUN_14

The simulation RUN_14 set the supply air flow from 7,366 cfm to 1,800 cfm, assuming 360 cfm/ton and 500 ft^2/ton.

Table A-14: Modification for RUN_14

RUN_13	RUN_14
`SPACE1-1 =ZONE ZONE-AIR=ZAIR SIZING-OPTION=ADJUST-LOADS` `ZONE-CONTROL=CONTROL ASSIGNED-CFM=7366 ..`	`SPACE1-1 =ZONE ZONE-AIR=ZAIR SIZING-OPTION=ADJUST-LOADS` `ZONE-CONTROL=CONTROL ASSIGNED-CFM=1800 ..`

A-3. Construction category

The *Construction* category defines input parameters for the residential building envelope according to the 2009 IECC requirements, including thermal insulation (U-value) of the floor, the roof, the walls, the door, and the windows, and solar absorptance of the roof and the walls.

A-3.1 Modification for RUN_15

The simulation RUN_15 in this category modified the floor thermal insulation. R-0 was used for the slab-on-glade floor in Climate Zone 2, based on Table 402.1.1 in 2009 IECC. R-0 was converted to layered input based on Winkelmann method (Winkelmann, 1998). In order to determine the average floor surface R-value (i.e., R-1.61 in this study), the following equation was used:

$$\text{CPXX} = \text{Carpet R-Value} \times \text{Carpet Fraction} + \text{Tile R-Value} \times (1 - \text{Carpet Fraction})$$

Where,

CPXX is the average R-value of the floor surface,
Carpet R-Value is the R-value of the carpet which was R-2.0 in this study,
Tile R-value is the R-value of the tile, which was R-0.05 in this study, and
Carpet Fraction is the carpet part fraction in the whole floor surface, which was 0.8 in this study.

Table A-15: Modification for RUN_15

RUN_14	RUN_15

`$ CONSTRUCTION AND GLASS-TYPES`
 	
`ROO-1 =LAYERS =MAT=(RG01,BR01,IN46,WD01) I-F-R .76 ..`
`WA-1-2 =LAYERS =MAT=(WD01,PW03,IN02,GP01) ..`
`WALL-1 =CONSTRUCTION U=0.069 ..`
`ROOF-1 =CONSTRUCTION U=0.048 ..`
`CLNG-1 =CONSTRUCTION U = 0.27 ..`
`SB-U =CONSTRUCTION U = 1.5 ..`
`FLOOR-1 =CONSTRUCTION U = 0.05 ..`
	`CPXX = MAT RESISTANCE = 1.61 ..`
	`$ SLAB-ON-GRADE`
	`MAT-FIC-1 = MAT RESISTANCE = 7.5436 ..`
	`SOIL-12IN = MAT THICKNESS = 1`
	`CONDUCTIVITY = 1`
	`DENSITY = 115`
	`SPECIFIC-HEAT = 0.1 ..`
	`LAY-SLAB-1 = LAYERS MATERIAL = (MAT-FIC-1,SOIL-12IN,CC03,CPXX)`
	`INSIDE-FILM-RES = 0.765 ..`
	
	`CON-SLAB-1 = CONSTRUCTION LAYERS = LAY-SLAB-1 ..`

`F1-1 =UNDERGROUND-FLOOR AREA = 2500 CONSTRUCTION = FLOOR-1 ..`
	`F1-1 = UNDERGROUND-FLOOR AREA = 2500`
	`CONSTRUCTION = CON-SLAB-1`
	`INSIDE-VIS-REFL = 0.2`
	`INSIDE-SOL-ABS = 0.8 ..`

A-3.2 Modification for RUN_16

The simulation RUN_16 modified the roof thermal insulation. R-30 was used for the roof, based on Section 402.2.2 in 2009 IECC. R-30 is equivalent to U-0.035 and the value was applied to layer input method with consideration of framing factor[11] 7%. The roof was divided into the insulation area, which takes 93% of the gross roof area, and the stud area, which takes 7% of gross roof area.

Table A-16: Modification for RUN_16

RUN_15

```
                      $ CONSTRUCTION AND GLASS-TYPES

ROO-1  =LAYERS =MAT=(RG01,BR01,IN46,WD01)  I-F-R .76  ..
WA-1-2 =LAYERS =MAT=(WD01,PW03,IN02,GP01)  ..
WALL-1         =CONSTRUCTION       LAYERS=WA-1-2  ..
ROOF-1         =CONSTRUCTION       LAYERS=ROO-1  ..
```

RUN_16

```
$  MATERIAL
ROOF_STUD     = MAT                    THICKNESS = 0.4583
                                       CONDUCTIVITY = 0.0667
                                       DENSITY = 32
                                       SPECIFIC-HEAT = 0.33  ..
BATT-ACEIL    = MAT                    THICKNESS = 0.696
                                       CONDUCTIVITY = 0.025
                                       DENSITY = 6
                                       SPECIFIC-HEAT = 0.2  ..
BATT-BCEIL    = MAT                    THICKNESS = 0.23767
                                       CONDUCTIVITY = 0.025
                                       DENSITY = 6
                                       SPECIFIC-HEAT = 0.2  ..
$  LAYERS
CLA_1         = LAYERS                 MAT = (BATT-ACEIL,GP02)
                                       INSIDE-FILM-RES = 0.765  ..
CLA_2         = LAYERS                 MAT = (BATT-BCEIL,ROOF_STUD,GP01)
                                       INSIDE-FILM-RES = 0.765  ..

$  CONSTRUCTION
CLNG-1        = CONSTRUCTION           LAYERS = CLA_1

                                       ROUGHNESS = 1       ..
CLNG-2        = CONSTRUCTION           LAYERS = CLA_2

                                       ROUGHNESS = 1       ..
```

[11] Framing factor: percentage of stud or joist area

TOP-1 =ROOF HEIGHT=50 WIDTH=50 X=0 Y=0 Z=8 AZIMUTH = 180 TILT=0 GND-REFLECTANCE=0 CONSTRUCTION = ROOF-1 ..	CEILING-1 = ROOF HEIGHT = 50 WIDTH = 46.5 X = 3.5 Y = 0 Z = 8 AZIMUTH = 180 TILT = 0 CONSTRUCTION = CLNG-1 .. CEILING-2 = ROOF HEIGHT = 50 WIDTH = 3.5 X = 0 Y = 0 Z = 8 AZIMUTH = 180 TILT = 0 CONSTRUCTION = CLNG-2 ..

A-3.3 Modification for RUN_17

The simulation RUN_17 modified the roof solar absorptance from 0.7 to 0.75 based on Table 405.5.2(1) in 2009 IECC.

Table A-17: Modification for RUN_17

RUN_16	RUN_17
$ CONSTRUCTION CLNG-1 = CONSTRUCTION LAYERS = CLA_1 ROUGHNESS = 1 .. CLNG-2 = CONSTRUCTION LAYERS = CLA_2 ROUGHNESS = 1 ..	$ CONSTRUCTION CLNG-1 = CONSTRUCTION LAYERS = CLA_1 ABSORPTANCE = 0.75 ROUGHNESS = 1 .. CLNG-2 = CONSTRUCTION LAYERS = CLA_2 ABSORPTANCE = 0.75 ROUGHNESS = 1 ..

A-3.4 Modification for RUN_18

The simulation RUN_18 modified the wall thermal insulation for Climate Zone 2 from U-0.069 to U-0.082, based on Table 402.1.3 in 2009 IECC and the wall U-value was applied to layered input method with consideration of framing factor 25%. The wall divided into two parts: one is the insulation area, which takes 75% of the net wall area, and does not contain a window nor door area. The other is a stud area, which takes 25% of the net wall area.

Table A-18: Modification for RUN_18

RUN_17	RUN_18
WA-1-2 =LAYERS =MAT=(WD01,PW03,IN02,GP01) .. WALL-1 =CONSTRUCTION LAYERS=WA-1-2 ..	WALL_STUD = MAT THICKNESS = 0.2917 CONDUCTIVITY = 0.0667 DENSITY = 32 SPECIFIC-HEAT = 0.33 .. WALL_BATT = MAT THICKNESS = 0.295 CONDUCTIVITY = 0.025 DENSITY = 6 SPECIFIC-HEAT = 0.2 .. WALL-1 = CONSTRUCTION LAYERS = WALL-1-1 ROUGHNESS = 2 .. WALL-2 = CONSTRUCTION LAYERS = WALL-1-2 ROUGHNESS = 2 ..
FRONT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=0 Y=0 Z=0 AZIMUTH = 180 ..	FRONT-1 = EXTERIOR-WALL HEIGHT = 8 WIDTH = 8.95 X = 0 Y = 0 Z = 0 AZIMUTH = 180 CONSTRUCTION = WALL-2 .. FRONT-2 = EXTERIOR-WALL HEIGHT = 8 WIDTH = 41.05 X = 8.95 Y = 0 Z = 0 AZIMUTH = 180 CONSTRUCTION = WALL-1 ..
RIGHT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=50 Y=0 Z=0 AZIMUTH = 90 ..	RIGHT-1 = EXTERIOR-WALL HEIGHT = 8 WIDTH = 9.57 X = 50 Y = 0 Z = 0 AZIMUTH = 90 CONSTRUCTION = WALL-2 .. RIGHT-2 = EXTERIOR-WALL HEIGHT = 8 WIDTH = 40.43 X = 50 Y = 9.57 Z = 0 AZIMUTH = 90 CONSTRUCTION = WALL-1 ..

BACK-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=50 Y=50 Z=0 AZIMUTH = 0 ..	BACK-1 = EXTERIOR-WALL HEIGHT = 8 WIDTH = 8.95 X = 50 Y = 50 Z = 0 AZIMUTH = 0 CONSTRUCTION = WALL-2 .. BACK-2 = EXTERIOR-WALL HEIGHT = 8 WIDTH = 41.05 X = 41.05 Y = 50 Z = 0 AZIMUTH = 0 CONSTRUCTION = WALL-1 ..
LEFT-1 =EXTERIOR-WALL HEIGHT = 8 WIDTH = 50 X=0 Y=50 Z=0 AZIMUTH = 270 ..	LEFT-1 = EXTERIOR-WALL HEIGHT = 8 WIDTH = 9.57 X = 0 Y = 50 Z = 0 AZIMUTH = 270 CONSTRUCTION = WALL-2 .. LEFT-2 = EXTERIOR-WALL HEIGHT = 8 WIDTH = 40.43 X = 0 Y = 40.43 Z = 0 AZIMUTH = 270 CONSTRUCTION = WALL-1 ..

A-3.5 Modification for RUN_19

The simulation RUN_19 modified the wall solar absorptance from 0.7 to 0.75, based on Table 405.5.2(1) in 2009 IECC.

Table A-19: Modification for RUN_19

RUN_18	RUN_19
WALL-1 = CONSTRUCTION LAYERS = WALL-1-1 ROUGHNESS = 2 .. WALL-2 = CONSTRUCTION LAYERS = WALL-1-2 ROUGHNESS = 2 ..	WALL-1 = CONSTRUCTION LAYERS = WALL-1-1 ABSORPTANCE = 0.75 ROUGHNESS = 2 .. WALL-2 = CONSTRUCTION LAYERS = WALL-1-2 ABSORPTANCE = 0.75 ROUGHNESS = 2 ..

A-3.6 Modification for RUN_20

The simulation RUN_20 modified the door thermal insulation from U-1.142 to U-0.65, based on Table 303.1.3(2) in 2009 IECC.

Table A-20: Modification for RUN_20

RUN_19	RUN_20
$ CONSTRUCTION AND GLASS-TYPES ROO-1 =LAYERS =MAT=(RG01,BR01,IN46,WD01) I-F-R .76 .. WA-1-2 =LAYERS =MAT=(WD01,PW03,IN02,GP01) .. WALL-1 =CONSTRUCTION U=0.082 ABSORPTANCE=0.75 .. ROOF-1 =CONSTRUCTION U=0.035 ABSORPTANCE=0.75 .. CLNG-1 =CONSTRUCTION U = 0.27 .. SB-U =CONSTRUCTION U = 1.5 .. FLOOR-1 =CONSTRUCTION U = 0.088 .. W-1 =GLASS-TYPE SHADING-COEF = 1 PANES = 2 GLASS-CONDUCTANCE = 0.574 .. DOORS =CONSTRUCTION U=1.142 ..	$ CONSTRUCTION AND GLASS-TYPES ROO-1 =LAYERS =MAT=(RG01,BR01,IN46,WD01) I-F-R .76 .. WA-1-2 =LAYERS =MAT=(WD01,PW03,IN02,GP01) .. WALL-1 =CONSTRUCTION U = 0.082 ABSORPTANCE=0.75 .. ROOF-1 =CONSTRUCTION U = 0.035 ABSORPTANCE=0.75 .. CLNG-1 =CONSTRUCTION U = 0.27 .. SB-U =CONSTRUCTION U = 1.5 .. FLOOR-1 =CONSTRUCTION U = 0.088 .. W-1 =GLASS-TYPE SHADING-COEF = 1 PANES = 2 GLASS-CONDUCTANCE = 0.574 .. DOORS =CONSTRUCTION U=0.65 ..

A-3.7 Modification for RUN_21

The simulation RUN_21 modified the window thermal conductance from U-0.516 to U-0.65 and modified SHGC from 0.87 to 0.3, based on Table 402.1.3 in 2009 IECC. Aluminum window frames were also applied to each window.

Table A-21: Modification for RUN_21

RUN_20	RUN_21
W-1 =GLASS-TYPE GLASS-TYPE-CODE = 3 PANES = 2 ..	W-1 = GLASS-TYPE GLASS-CONDUCTANCE = 0.3823 SHADING-COEF = 0.426 FRAME-CONDUCTANCE = 3.037 PANES = 1 ..
WF-1 =WINDOW WIDTH = 18.75 X = 15.625 ..	WF-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 ..

WR-1 =WINDOW WIDTH = 18.75 X = 15.625 ..	WR-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 ..
WB-1 =WINDOW WIDTH = 18.75 X = 15.625 ..	WB-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 ..
WL-1 =WINDOW WIDTH = 18.75 X = 15.625 ..	WL-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 ..

A-3.8 Modification for RUN_22

The simulation RUN_22 modified the infiltration rate from 0.25 Air Change per Hour (ACH) to 0.35 ACH, based on Table 405.5.2(1) in 2009 IECC. On this simulation run modification, the infiltration method also changed from the ACH method to the Sherman-Grimsrud model, which was described in section 3.3. In addition, 0.24 of the shielding-coefficient[12], which is the DOE-2.1e default value, was used.

Table A-22: Modification for RUN_22

RUN_21	RUN_22
BUILDING-LOCATION LATITUDE=29.5 LONGITUDE=95 ALTITUDE=68 TIME-ZONE=6 AZIMUTH=0 ..	BUILDING-LOCATION LATITUDE=29.5 LONGITUDE=95 ALTITUDE=68 TIME-ZONE=6 AZIMUTH=0 SHIELDING-COEF = 0.24 ..
OFFICE =SPACE-CONDITIONS PEOPLE-SCHEDULE =OCCUPY-1 NUMBER-OF-PEOPLE =0 PEOPLE-HEAT-GAIN =400 LIGHTING-SCHEDULE =LIGHTS-1 LIGHTING-TYPE =REC-FLUOR-RV LIGHT-TO-SPACE =.80 LIGHTING-W/SQFT =1.5 EQUIP-SCHEDULE =EQUIP-1 EQUIPMENT-W/SQFT =1 INF-METHOD =AIR-CHANGE AIR-CHANGES/HR =0.25 INF-SCHEDULE =INFIL-SCH ..	OFFICE =SPACE-CONDITIONS PEOPLE-SCHEDULE =OCCUPY-1 NUMBER-OF-PEOPLE =0 PEOPLE-HEAT-GAIN =400 LIGHTING-SCHEDULE =LIGHTS-1 LIGHTING-TYPE =REC-FLUOR-RV LIGHT-TO-SPACE =.80 LIGHTING-W/SQFT =1.5 EQUIP-SCHEDULE =EQUIP-1 EQUIPMENT-W/SQFT =1 INF-METHOD = S-G FRAC-LEAK-AREA = 0.0004321 HOR-LEAK-FRAC = 0.4 NEUTRAL-LEVEL = 0.5 INF-SCHEDULE = INFIL-SCH ..

[12] 0.24 of the shielding-coefficient represents the moderate local shielding.

A-3.9 Modification for RUN_23

The simulation RUN_23 modified the ground reflectance from 0 to 0.24. This was an assumption that the residential building was surrounded by grass.

Table A-23: Modification for RUN_23

RUN_22	RUN_23
$ SET DEFAULT VALUES SET-DEFAULT FOR SPACE FLOOR-WEIGHT=0 .. SET-DEFAULT FOR WINDOW HEIGHT= 4.222 GLASS-TYPE = W-1 Y = 2 ..	$ SET DEFAULT VALUES SET-DEFAULT FOR SPACE FLOOR-WEIGHT=0 .. SET-DEFAULT FOR EXTERIOR-WALL GND-REFLECTANCE = 0.24 SET-DEFAULT FOR WINDOW HEIGHT= 4.222 GLASS-TYPE = W-1 Y = 2 ..
CEILING-1 = ROOF HEIGHT = 50 WIDTH = 46.5 X = 3.5 Y = 0 Z = 8 AZIMUTH = 180 TILT = 0 CONSTRUCTION = CLNG-1 .. CEILING-2 = ROOF HEIGHT = 50 WIDTH = 3.5 X = 0 Y = 0 Z = 8 AZIMUTH = 180 TILT = 0 CONSTRUCTION = CLNG-2 ..	CEILING-1 = ROOF HEIGHT = 50 WIDTH = 46.5 X = 3.5 Y = 0 Z = 8 AZIMUTH = 180 TILT = 0 GND-REFLECTANCE = 0.24 CONSTRUCTION = CLNG-1 .. CEILING-2 = ROOF HEIGHT = 50 WIDTH = 3.5 X = 0 Y = 0 Z = 8 AZIMUTH = 180 TILT = 0 GND-REFLECTANCE = 0.24 CONSTRUCTION = CLNG-2 ..

A-4. Internal Gain category

The *Internal Gain* category defines input parameters for the energy use of the lighting and the equipment.

A-4.1 Modification for RUN_24 and RUN_25

The simulation RUN_24 and RUN_25 in this category modified the lighting power density from 1.5 W/ft^2 to 0.1951 W/ft^2 and the equipment power density from 1.0 W/ft^2 to 0.2632 W/ft^2, respectively. “Internal gain” value was calculated based on the Table 405.5.2(1) in 2009 IECC, which was described in section 3.4 and distributed to lighting energy consumption and equipment energy consumption based on the energy use of the American residential benchmark building on NREL report (NREL, 2005).

Table A-24: Modification for RUN_24

RUN_23	RUN_24
$ GENERAL SPACE DEFINITION	$ GENERAL SPACE DEFINITION
OFFICE =SPACE-CONDITIONS PEOPLE-SCHEDULE =OCCUPY-1	OFFICE =SPACE-CONDITIONS PEOPLE-SCHEDULE =OCCUPY-1
NUMBER-OF-PEOPLE =50	NUMBER-OF-PEOPLE =0
PEOPLE-HEAT-GAIN =400	PEOPLE-HEAT-GAIN =400
LIGHTING-SCHEDULE =LIGHTS-1	LIGHTING-SCHEDULE =LIGHTS-1
LIGHTING-TYPE =REC-FLUOR-RV	LIGHTING-TYPE =REC-FLUOR-RV
LIGHT-TO-SPACE =.80	LIGHT-TO-SPACE =.80
LIGHTING-W/SQFT =1.5	LIGHTING-W/SQFT =0.1951
EQUIP-SCHEDULE =EQUIP-1	EQUIP-SCHEDULE =EQUIP-1
EQUIPMENT-W/SQFT =1	EQUIPMENT-W/SQFT =1
INF-METHOD =AIR-CHANGE	INF-METHOD =AIR-CHANGE
AIR-CHANGES/HR =0.25	AIR-CHANGES/HR =0.35
INF-SCHEDULE =INFIL-SCH ..	INF-SCHEDULE =INFIL-SCH ..

Table A-25: Modification for RUN_25

RUN_24	RUN_25
99 $ GENERAL SPACE DEFINITION 100 101 OFFICE =SPACE-CONDITIONS PEOPLE-SCHEDULE =OCCUPY-1 102 NUMBER-OF-PEOPLE =0 103 PEOPLE-HEAT-GAIN =400 104 LIGHTING-SCHEDULE =LIGHTS-1 105 LIGHTING-TYPE =REC-FLUOR-RV 106 LIGHT-TO-SPACE =.80 107 LIGHTING-W/SQFT =0.1951 108 EQUIP-SCHEDULE =EQUIP-1 109 $\boxed{\text{EQUIPMENT-W/SQFT =1}}$ 110 INF-METHOD =AIR-CHANGE 111 AIR-CHANGES/HR =0.35 112 INF-SCHEDULE =INFIL-SCH ..	99 $ GENERAL SPACE DEFINITION 100 101 OFFICE =SPACE-CONDITIONS PEOPLE-SCHEDULE =OCCUPY-1 102 NUMBER-OF-PEOPLE =0 103 PEOPLE-HEAT-GAIN =400 104 LIGHTING-SCHEDULE =LIGHTS-1 105 LIGHTING-TYPE =REC-FLUOR-RV 106 LIGHT-TO-SPACE =.80 107 LIGHTING-W/SQFT =0.1951 108 EQUIP-SCHEDULE =EQUIP-1 109 $\boxed{\text{EQUIPMENT-W/SQFT =0.2632}}$ 110 INF-METHOD =AIR-CHANGE 111 AIR-CHANGES/HR =0.35 112 INF-SCHEDULE =INFIL-SCH ..

A-5. Schedule category

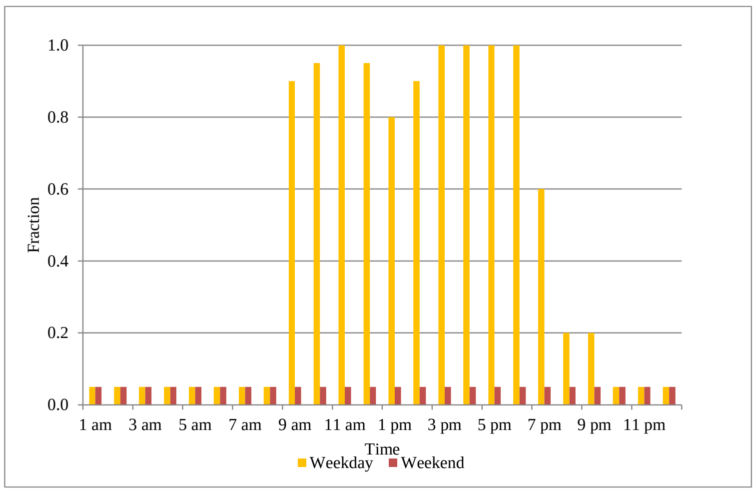
The *Schedule* category defines input parameters for the residential model to have constant schedules for lighting, equipment, and infiltration. In addition, the *Schedule* category defines the interior shading.

A-5.1 Modification for RUN_26

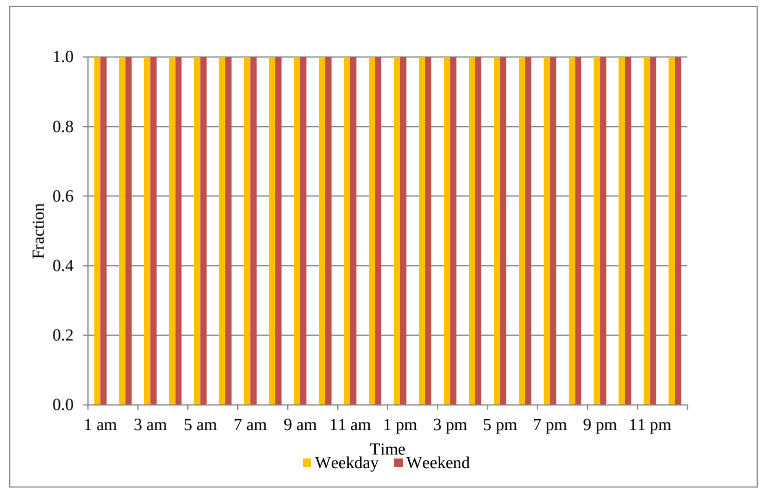
The simulation RUN_26 in this category set the lighting system to be always on. The lighting schedule is shown in Figure A-4.

Table A-26: Modification for RUN_26

Run_25	Run_26
$ LIGHTING SCHEDULE LT-1 =DAY-SCHEDULE (1,8) (0.05) (9,14) (0.9,0.95,1.0,0.95,0.8,0.9) (15,18) (1.0) (19,21) (0.6,0.2,0.2) (22,24) (0.05) .. LT-2 =DAY-SCHEDULE (1,24) (0.05) .. LT-WEEK =WEEK-SCHEDULE (MON,FRI) LT-1 (WEH) LT-2 .. LIGHTS-1 =SCHEDULE THRU DEC 31 LT-WEEK ..	$ LIGHTING SCHEDULE LT-1 =DAY-SCHEDULE (1,24) (1) .. LT-2 =DAY-SCHEDULE (1,24) (1) .. LT-WEEK =WEEK-SCHEDULE (MON,FRI) LT-1 (WEH) LT-2 .. LIGHTS-1 =SCHEDULE THRU DEC 31 LT-WEEK ..



RUN_25



RUN_26

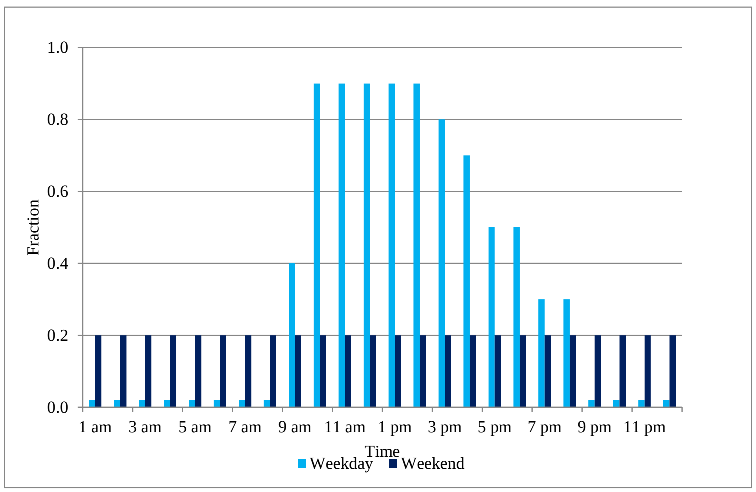
Figure A-4: Lighting Schedules for RUN_25 and RUN_26

A-5.2 Modification for RUN_27

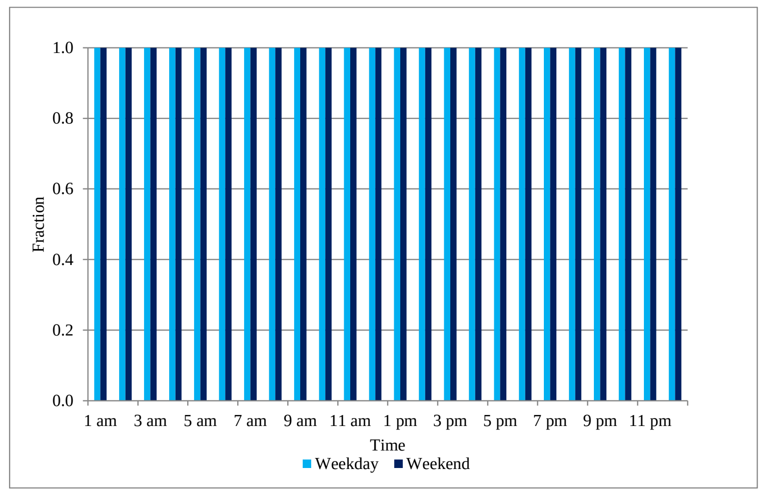
The simulation RUN_27 in this category set the equipment system to be always on. The equipment schedule is shown in Figure A-5.

Table A-27: Modification for RUN_27

RUN_26	RUN_27
$ OFFICE EQUIPMENT SCHEDULE	$ OFFICE EQUIPMENT SCHEDULE
EQ-1 =DAY-SCHEDULE (1,8) (0.02)	EQ-1 =DAY-SCHEDULE (1,24) (1) ..
(9,14) (0.4,0.9,0.9,0.9,0.9,0.9)	
(15,20) (0.8,0.7,0.5,0.5,0.3,0.3)	
(21,24) (0.02) ..	
EQ-2 =DAY-SCHEDULE (1,24) (0.2) ..	EQ-2 =DAY-SCHEDULE (1,24) (1) ..
EQ-WEEK =WEEK-SCHEDULE (MON,FRI) EQ-1 (WEH) EQ-2 ..	EQ-WEEK =WEEK-SCHEDULE (MON,FRI) EQ-1 (WEH) EQ-2 ..
EQUIP-1 =SCHEDULE THRU DEC 31 EQ-WEEK ..	EQUIP-1 =SCHEDULE THRU DEC 31 EQ-WEEK ..



RUN_26



RUN_27

Figure A-5: Equipment Schedules for RUN_26 and RUN_27

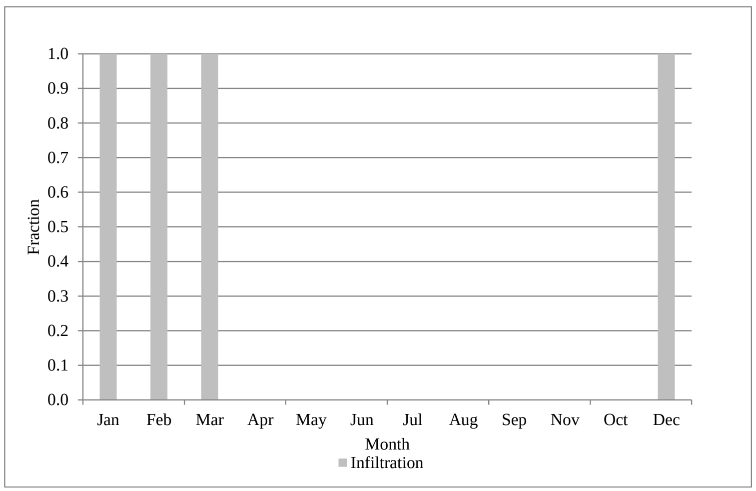
A-5.3 Modification for RUN_28

The simulation RUN_28 in this category set the infiltration to be always on. The infiltration schedule is shown in Figure A-6.

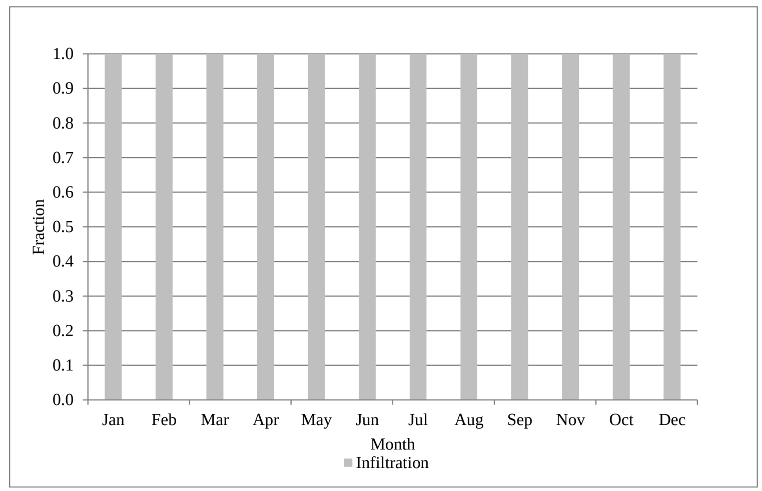
Table A-28: Modification for RUN_28

RUN_27	RUN_28

`$ INFILTRATION SCHEDULE`
 	
`INFIL-SCH =SCHEDULE THRU MAR 31 (ALL) (1,24) (1)`
`THRU OCT 31 (ALL) (1,24) (0)`
`THRU DEC 31 (ALL) (1,24) (1) ..`
	`$ INFILTRATION SCHEDULE`
	
	`INFIL-SCH =SCHEDULE THRU MAR 31 (ALL) (1,24) (1)`
	`THRU OCT 31 (ALL) (1,24) (1)`
	`THRU DEC 31 (ALL) (1,24) (1) ..`



RUN_27



RUN_28

Figure A-6: Infiltration Schedules for RUN_27 and RUN_28

A-5.4 Modification for RUN_29

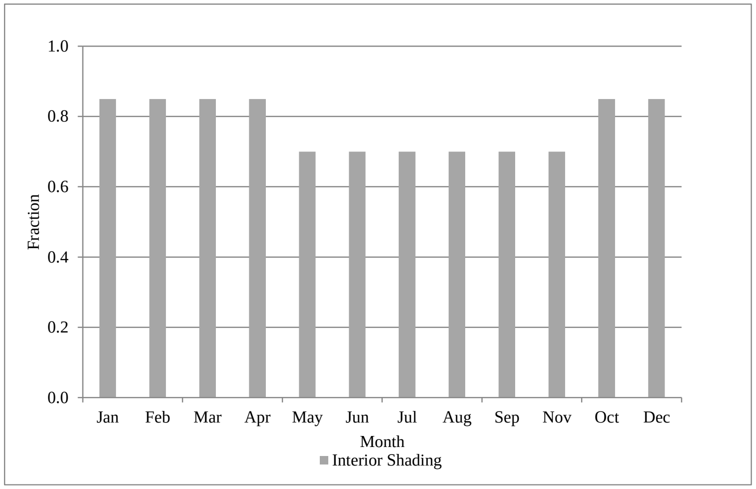
The simulation RUN_29 in this category set the schedule of the interior shading[13] for the windows based on Table 405.5.2(1) in 2009 IECC. The interior shading schedule is shown in Figure A-8.

Table A-29: Modification for RUN_29

RUN_28	RUN_29
No Interior Shading Schedule	$ INTERIOR SHADING SCHEDULE SH-1 = SCHEDULE THRU APR 30 (ALL) (1,24) (0.85) THRU OCT 31 (ALL) (1,24) (0.7) THRU DEC 31 (ALL) (1,24) (0.85) ..
WF-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 ..	WF-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 SHADING-SCHEDULE = SH-1 ..
WR-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 ..	WR-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 SHADING-SCHEDULE = SH-1 ..
WB-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 ..	WB-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 SHADING-SCHEDULE = SH-1 ..
WL-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 ..	WL-1 = WINDOW WIDTH = 17.972 X = 3.125 FRAME-WIDTH = 0.389 SHADING-SCHEDULE = SH-1 ..

[13] Interior shading represents percentage of light transmitted from outside to inside by blinds or drapes operation. The multipliers in the Interior Shading schedule are specified in terms of: 1.0 means no shading, 0.0 means full shading.

No Interior Shading



RUN_28 RUN_29

Figure A-7: Interior Shading Schedules for RUN_28 and RUN_29

A-6. DHW category

The last category is the *DHW* category, which defines input for a domestic hot water heater system.

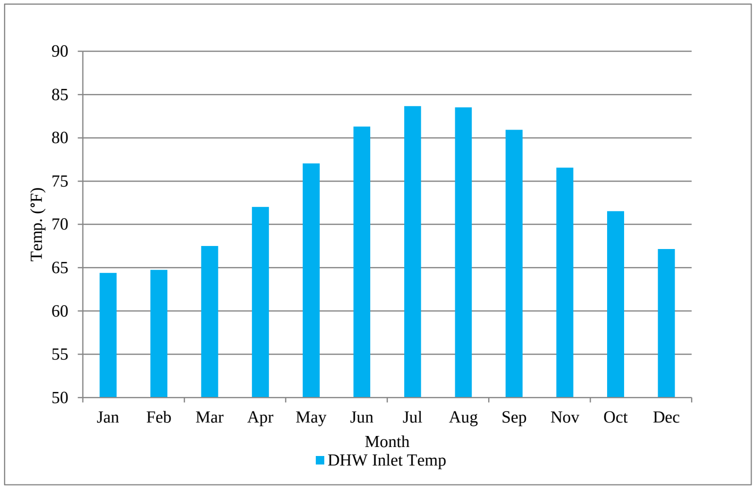
A-6.1 Modification for RUN_30

The simulation RUN_30 in this category defined the residential electric DHW system. 50 gallons of the hot water tank size, 18,766 Btu/hr of the burner capacity, and 1 of the energy factor for electric water heater, which is default of the DOE-2.1e program, were used. The IC3 DHW inlet water temperatures, which was calculated using Equation 5 in the NREL report (NREL, 2004), were referenced. This model used the IC3 water heater standby loss value, which was calculated based on the Water Heater Analysis Model (WHAM) (Lutz, 1998).

Table A-30: Modification for RUN_30

RUN_29	RUN_30
No DHW system setting	DHW-SCHED = SCHEDULE THRU DEC 31 (ALL) (1,24) (1) .. DHWINLETSCH-1 = SCHEDULE THRU JAN 31 (ALL) (1,24) (64.39) THRU FEB 28 (ALL) (1,24) (64.74) THRU MAR 31 (ALL) (1,24) (67.52) THRU APR 30 (ALL) (1,24) (72.02) THRU MAY 31 (ALL) (1,24) (77.05) THRU JUN 30 (ALL) (1,24) (81.3) THRU JUL 31 (ALL) (1,24) (83.67) THRU AUG 31 (ALL) (1,24) (83.54) THRU SEP 30 (ALL) (1,24) (80.94) THRU OCT 31 (ALL) (1,24) (76.55) THRU NOV 30 (ALL) (1,24) (71.52) THRU DEC 31 (ALL) (1,24) (67.15) ..
HP-1 =PLANT-ASSIGNMENT SYSTEM-NAMES=(SYST-1) HP-LOOP-HEATING= FROM-SYSTEMS HP-LOOP-COOLING= FROM-SYSTEMS .. END ..	HP-1 =PLANT-ASSIGNMENT SYSTEM-NAMES=(SYST-1) DHW-TYPE = ELECTRIC DHW-SIZE = 50 DHW-GAL/MIN = 0.0486 DHW-SCH = DHW-SCHED DHW-INLET-T-SCH = DHWINLETSCH-1 DHW-SUPPLY-T = 120 DHW-HEAT-RATE = 18766 DHW-LOSS = 0.00657 DHW-EIR = 1 HP-LOOP-HEATING= FROM-SYSTEMS HP-LOOP-COOLING= FROM-SYSTEMS ..

None



RUN_29 RUN_30

Figure A-8: Domestic Hot Water Inlet Temperature Schedules for RUN_29 and RUN_30

Appendix B: IC3 Input Parameter Setting

This appendix shows the input parameter setting for IC3 to compare the simulation results against RUN_30. The input parameters in IC3 include the Project Information, Floors, Windows, Insulation/Mechanical, HVAC/DHW, Roof, and Horizontal Projections.

Figure B-1 shows the screenshot of IC3 input parameters for the Project Information including the choice of the energy code, the site address, and the orientation. In this study, 2009 IECC was set for this model; Harris County was set for Houston, TX; and South was set for the direction the front of the house was facing.

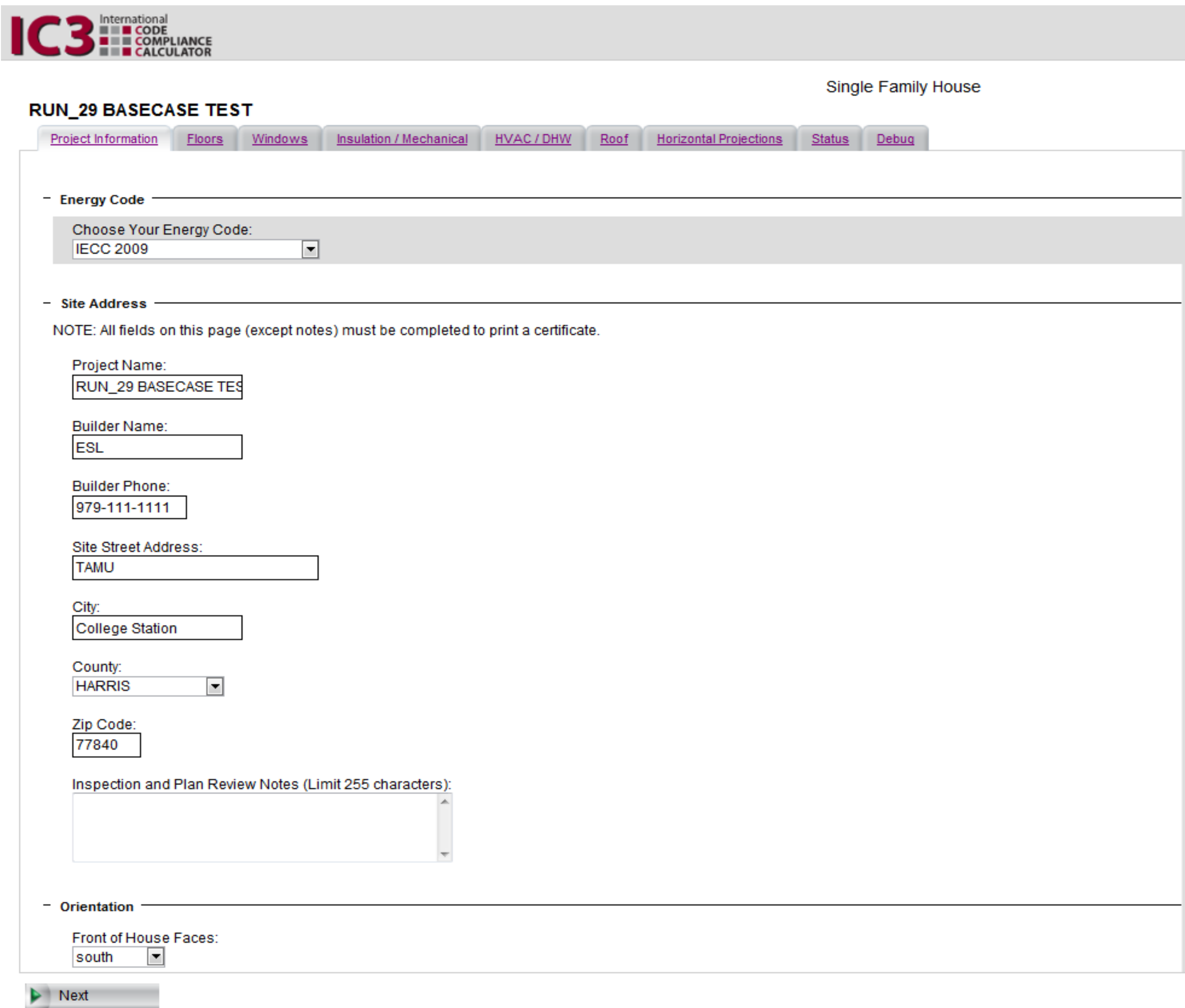


Figure B-1: Screenshot of IC3 Input Parameters for Project Information

Figure B-2 shows the screenshot of IC3 input parameters for the Floors. The input parameters include a number of floors, geometry of the floor, a number of bedrooms, and type of the building structure. This study set single floor, 2,500 ft^2 for the conditioned floor area, 200 ft for perimeter of conditioned area, 8 ft for average ceiling height, four bedrooms, and slab-on-grade foundation type.

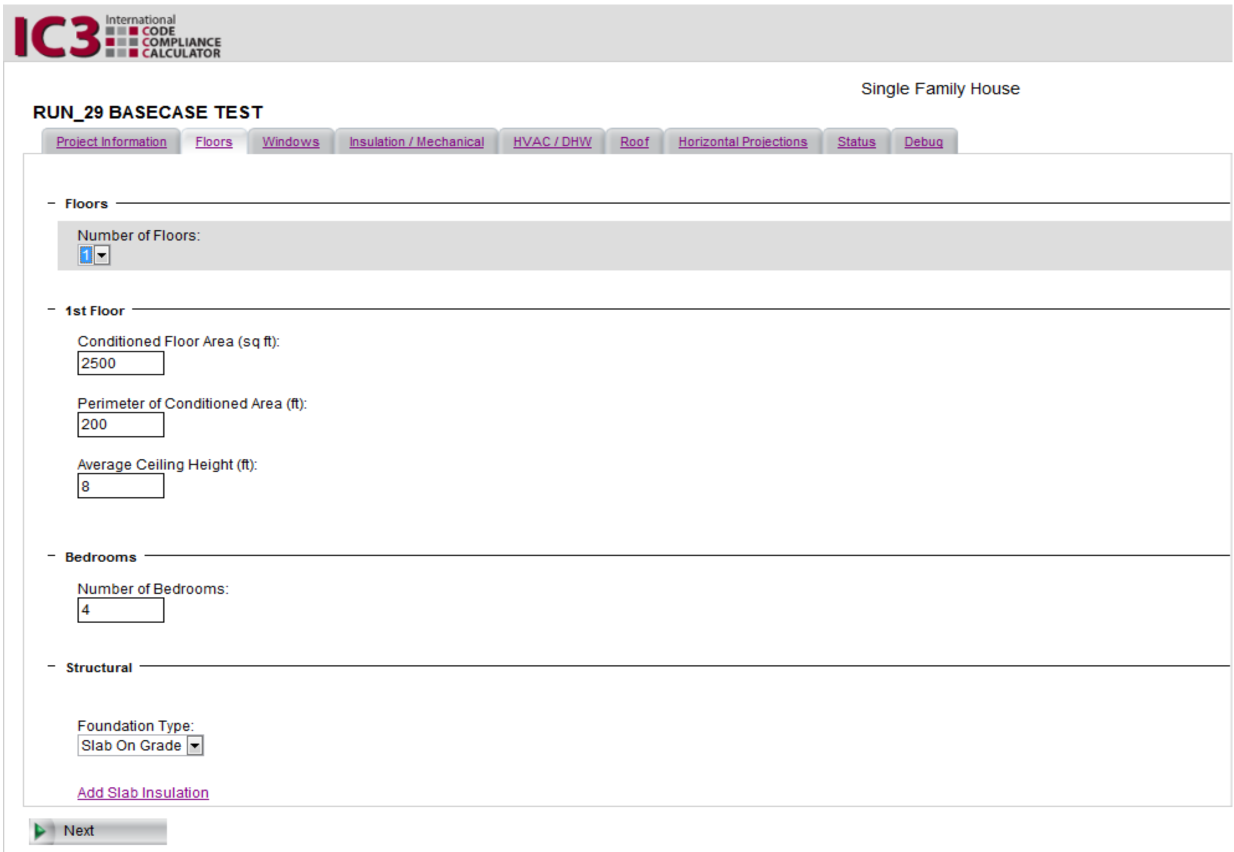


Figure B-2: Screenshot of IC3 Input Parameters for Floors

Figure B-3 shows the screenshot of IC3 input parameters for the Windows. The input parameters include the solar heat gain coefficient, U-factor, and areas of the windows at each wall. This study set 0.3 for SHGC, 0.65 for U-factor, and 93.75 ft^2 for each window area.

Figure B-4 shows the screenshot of IC3 input parameters for the Insulation/Mechanical. The input parameters include the mechanical system location, infiltration, and insulation for wall and roof/ceiling. This study set the mechanical system location in the conditioned space, 6.99 for the blower door test, 11.8 for wall cavity insulation R-value, 0 for insulation wall sheathing R-value, brick for the exterior wall finish, and 27.84 for the total roof/ceiling insulation R-value.

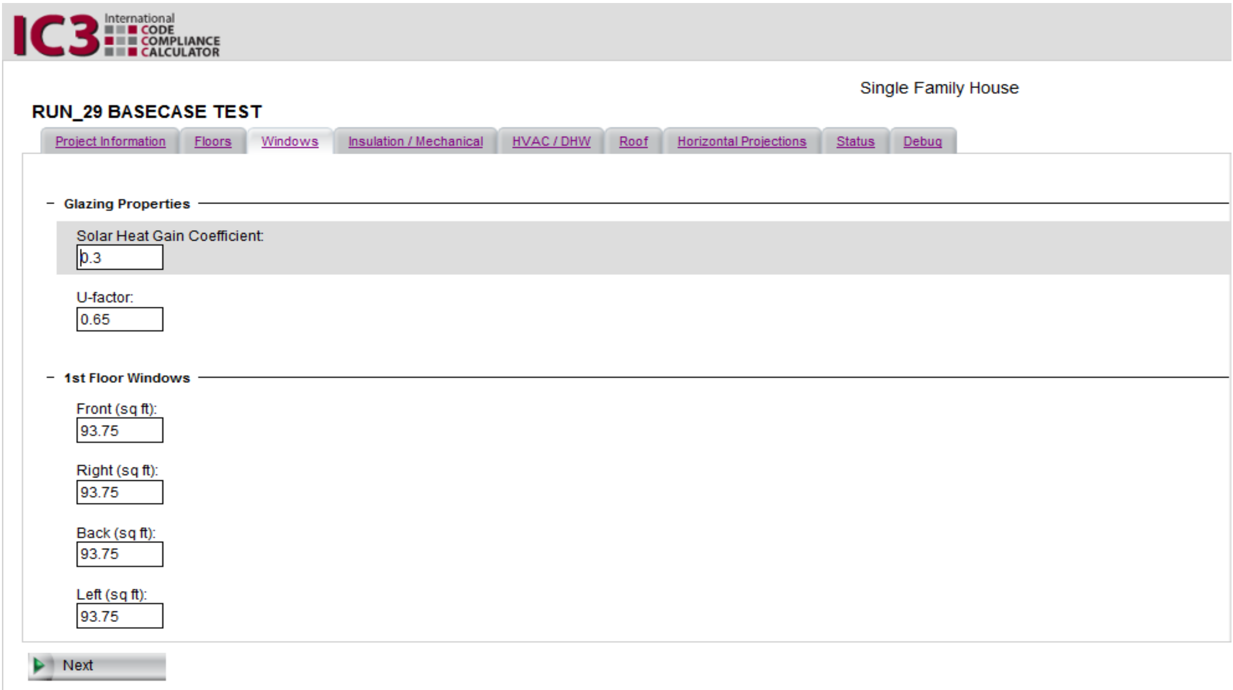


Figure B-3: Screenshot of IC3 Input Parameters for Windows

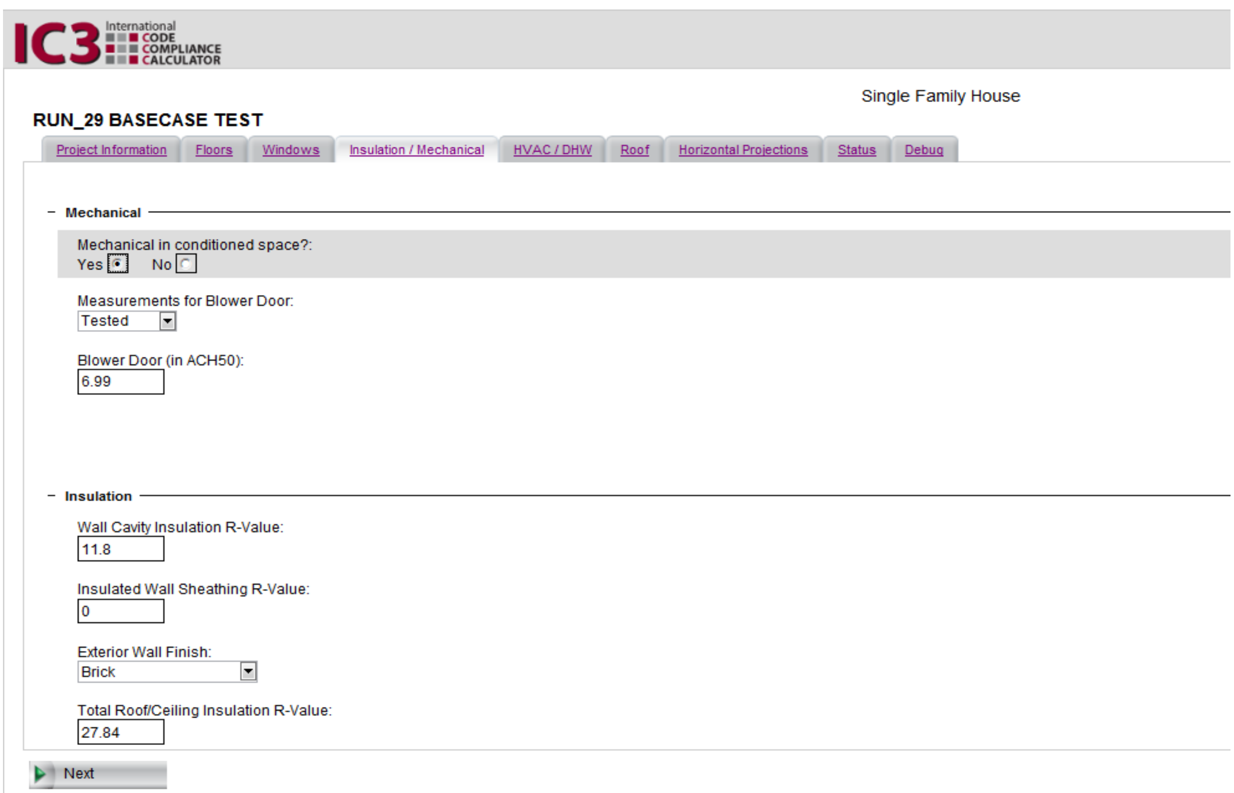


Figure B-4: Screenshot of IC3 Input Parameters for Insulation/Mechanical

Figure B-5 shows the screenshot of IC3 input parameters for the HVAC/DHW. The input parameters include the heating system type, heating efficiency, cooling efficiency, cooling system size, type of the water heater, and energy factor of the water heater. This study set heat pump performance efficiency as 7.7 HSPF, SEER 13, 5 tons for the heating and cooling parameters. In addition, this study set 0.904 for energy factor for an electric water heater, and did not use the detailed DHW input.

Figure B-6 shows the screenshot of IC3 input parameters for the Roof. The input parameters include the roof covering material, usage of the radiant barrier, and ceiling area. This study set Comp Shingle for the roof covering material and did not use the radiant barrier. In addition, this study set 2,500 ft^2 for the cathedral ceiling area.

Figure B-7 shows the screenshot of IC3 input parameters for the Horizontal Projections. The input parameters include the dimension of the horizontal projections for each wall. This study did not use any projections.

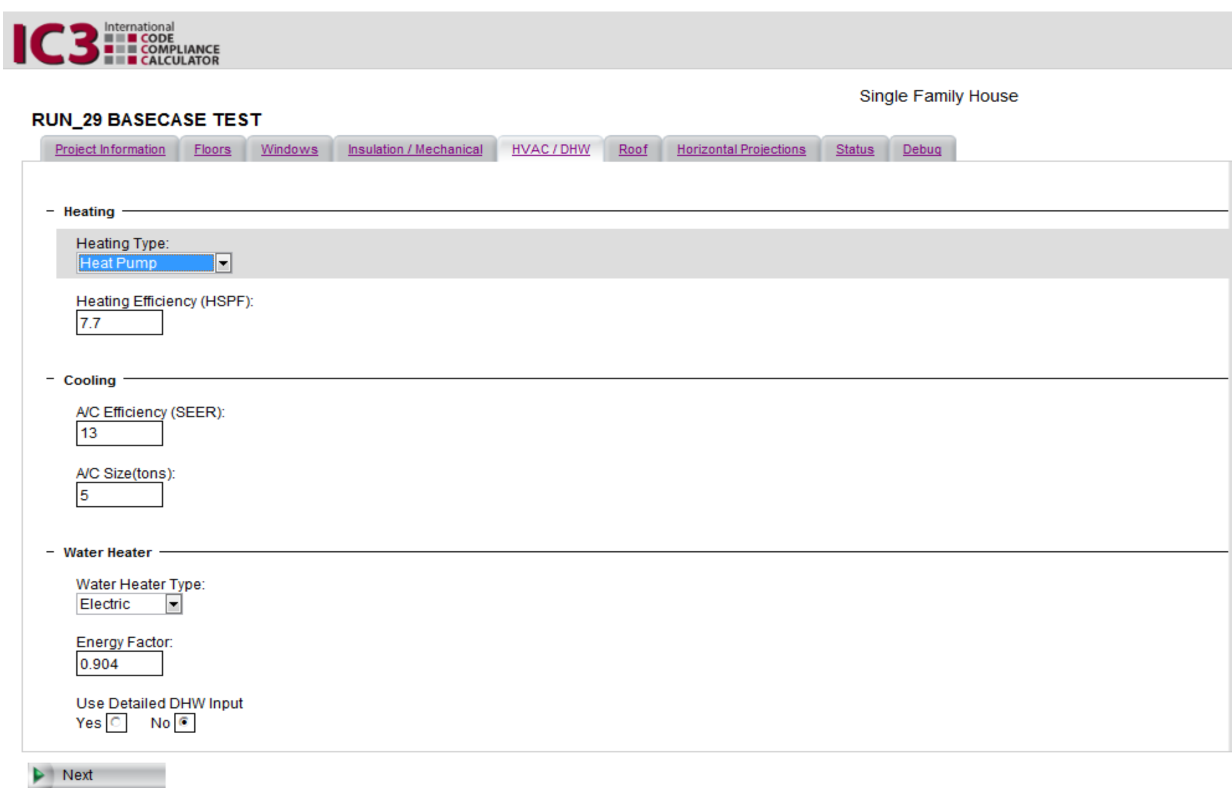


Figure B-5: Screenshot of IC3 Input Parameters for HVAC/DHW

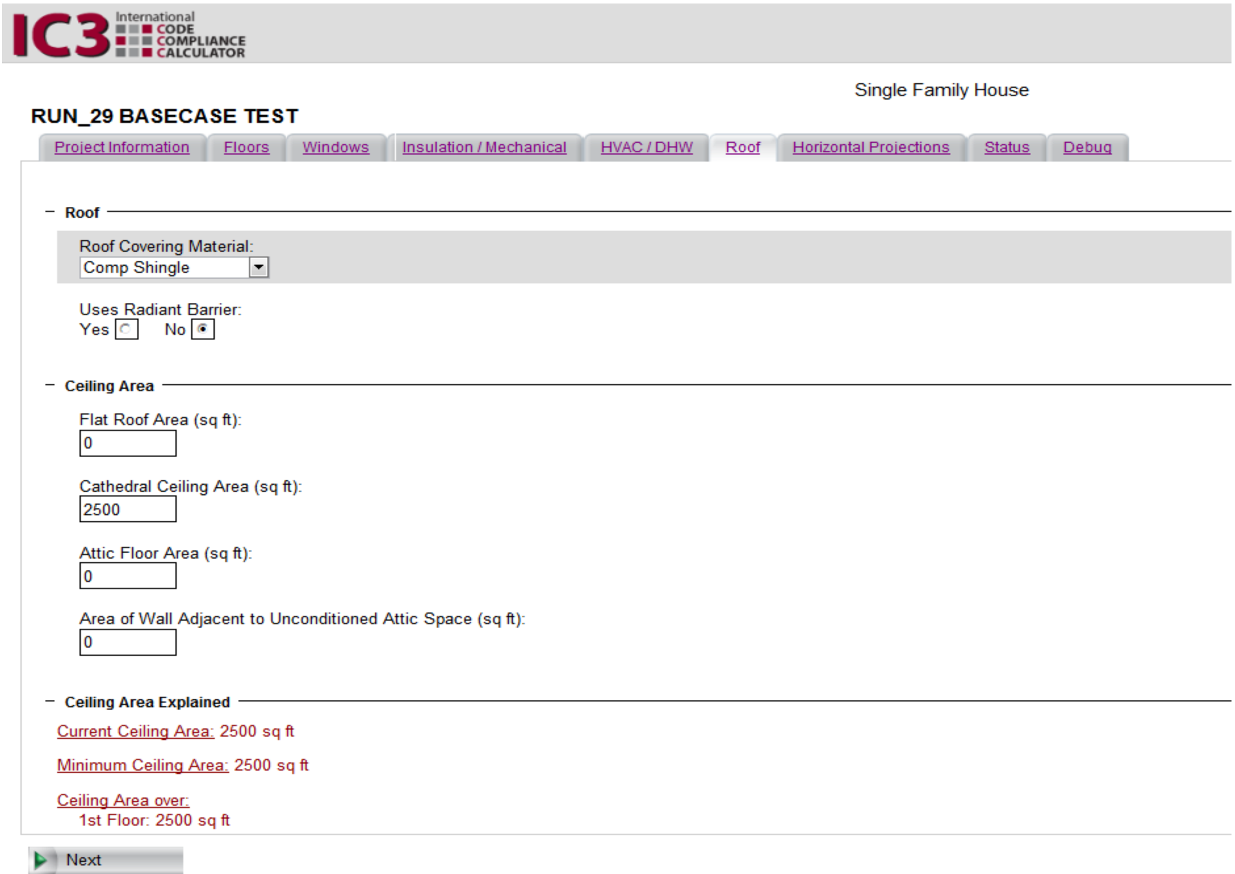


Figure B-6: Screenshot of IC3 Input Parameters for Roof

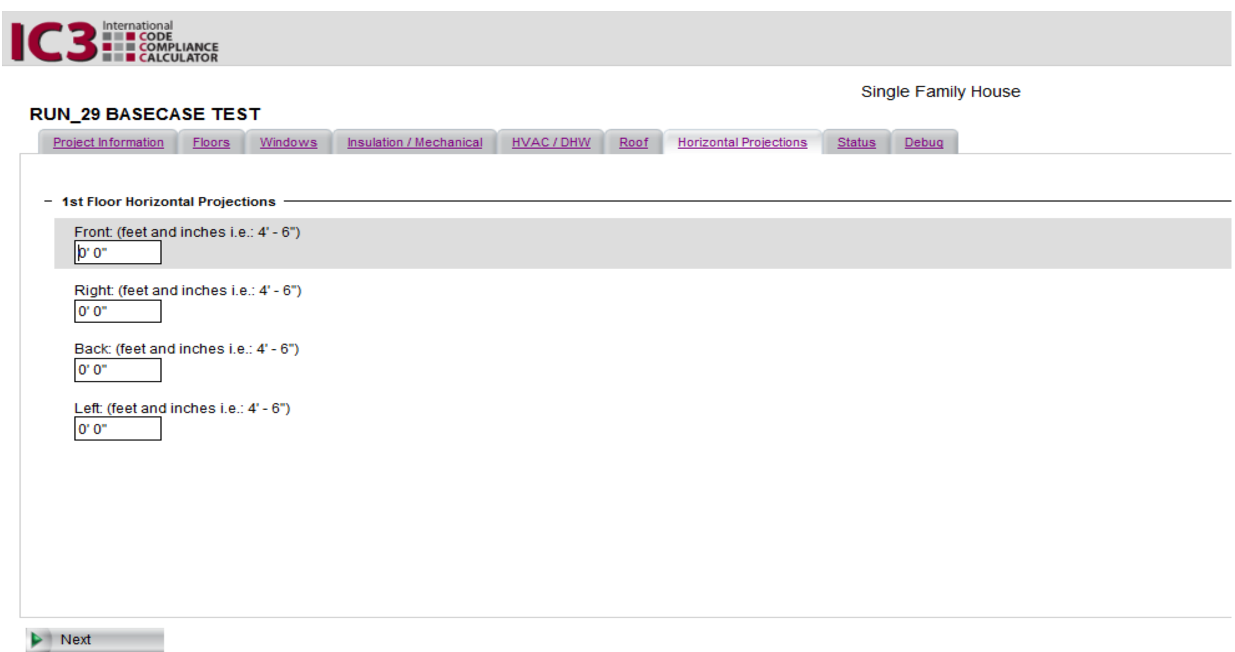


Figure B-7: Screenshot of IC3 Input Parameters for Horizontal Projections

Appendix C: REM/Rate Input Parameter Setting

This appendix shows the input parameter setting for REM/Rate version 14.1 to compare simulation results against RUN_30. The inputs in REM/Rate have 12 sections, including site information, building information, slab floors, above-grade walls, windows and glass doors, doors, ceilings, mechanical equipment, ducts systems, infiltration and ventilation, lightings and appliances, and mandatory requirements. Figure C-1 through Figure C-19 present the screenshots of the REM/Rate inputs.

Figure C-1 shows the screenshot of the REM/Rate input parameters for the site information. The inputs include a choice of the climate location, and utility information. This study used Houston, TX for the climate location, and did not use the utility information since this study does not analyze the energy cost.

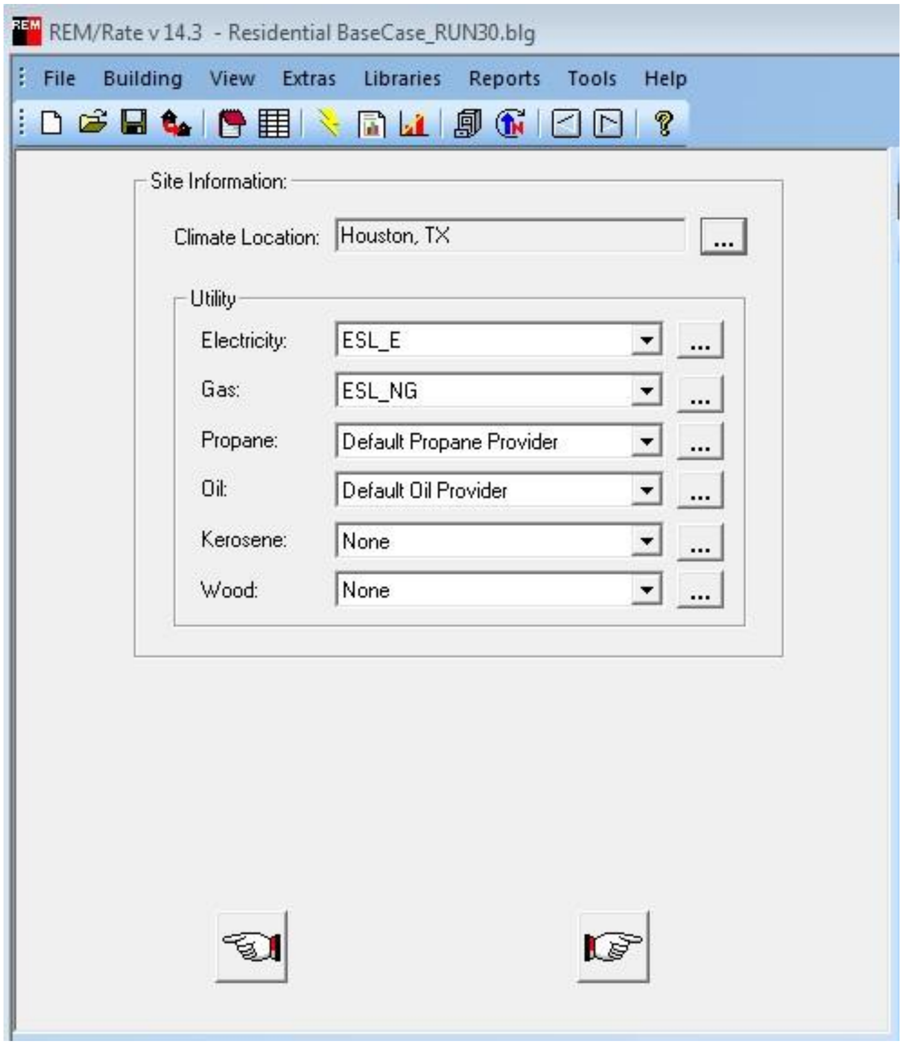


Figure C-1: Screenshot of REM/Rate Input for Site Information

Figure C-2 shows the screenshot of the REM/Rate input parameters for the building information. The inputs include the conditioned floor area, the volume of conditioned space, the year built, the housing type, the building stories, the number of bedroom, and the foundation type. This study set single floor, 2,500 ft^2 for the conditioned floor area, 20,000 ft^3 for the conditioned floor volume, 2009 for the year built, single-family detached, four bedrooms, and the slab-on-grade foundation type.

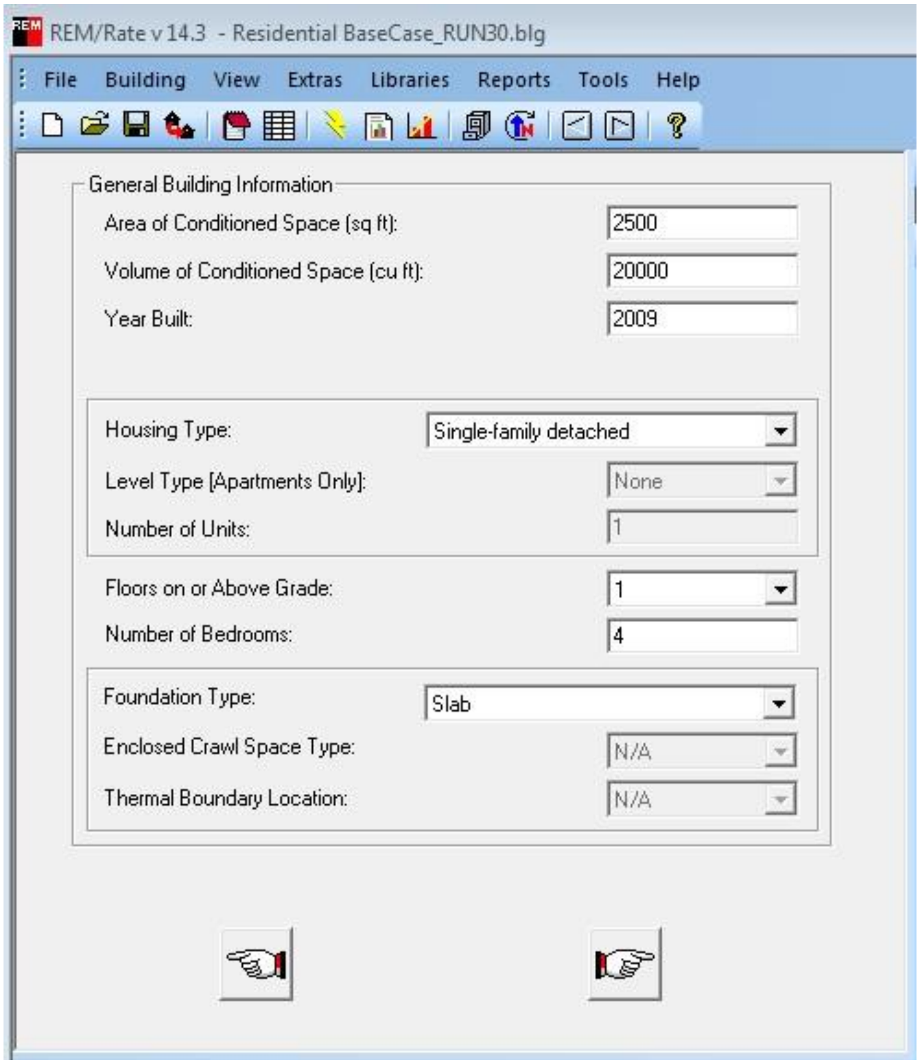


Figure C-2: Screenshot of REM/Rate Input for Building Information

Figure C-3 shows the screenshot of the REM/Rate input parameter for the slab floors information. The inputs include the slab area, the length of the full perimeter, the slab floor depth, the length of the total exposed perimeter, and the length of the on-grade exposed perimeter. This study used 2,500 ft^2 for the slab area, 200 ft for the full perimeter, 0 ft for the depth below grade, 200 ft for the exposed perimeter, and 200 ft for the on-grade exposed perimeter.

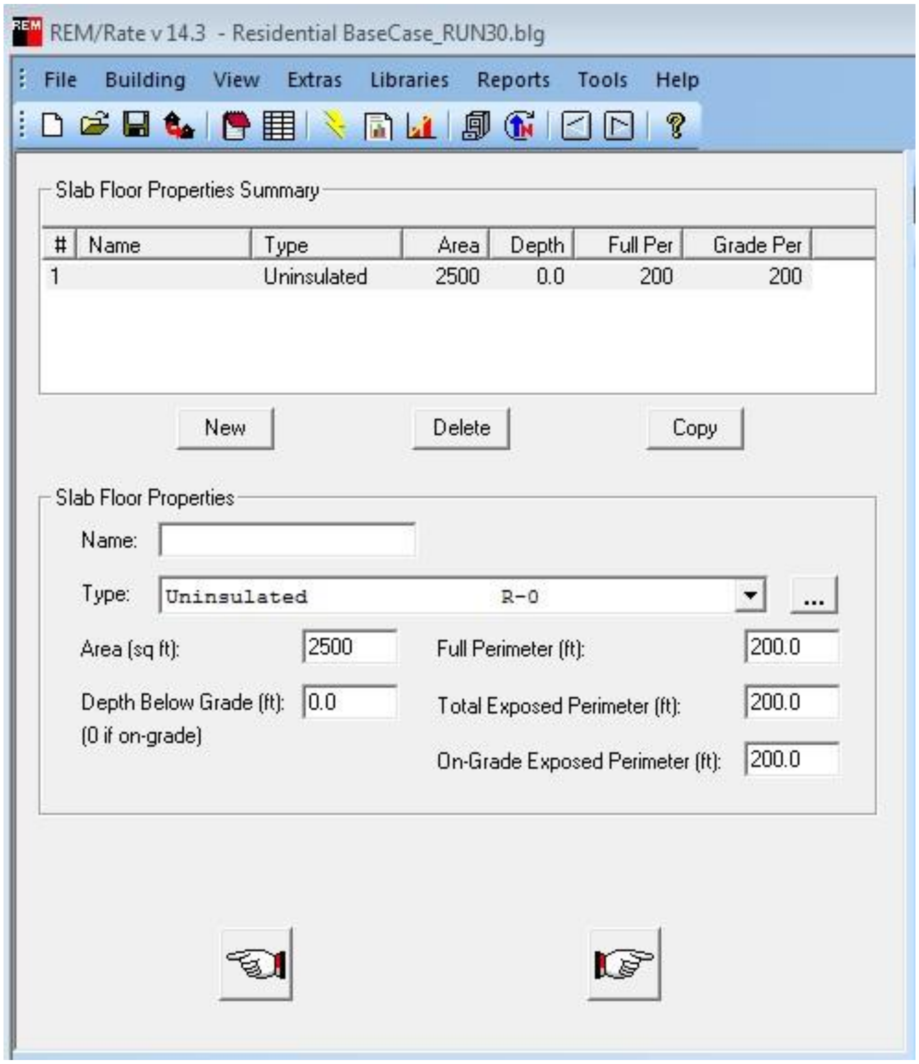


Figure C-3: Screenshot of REM/Rate Input for Slab Floors

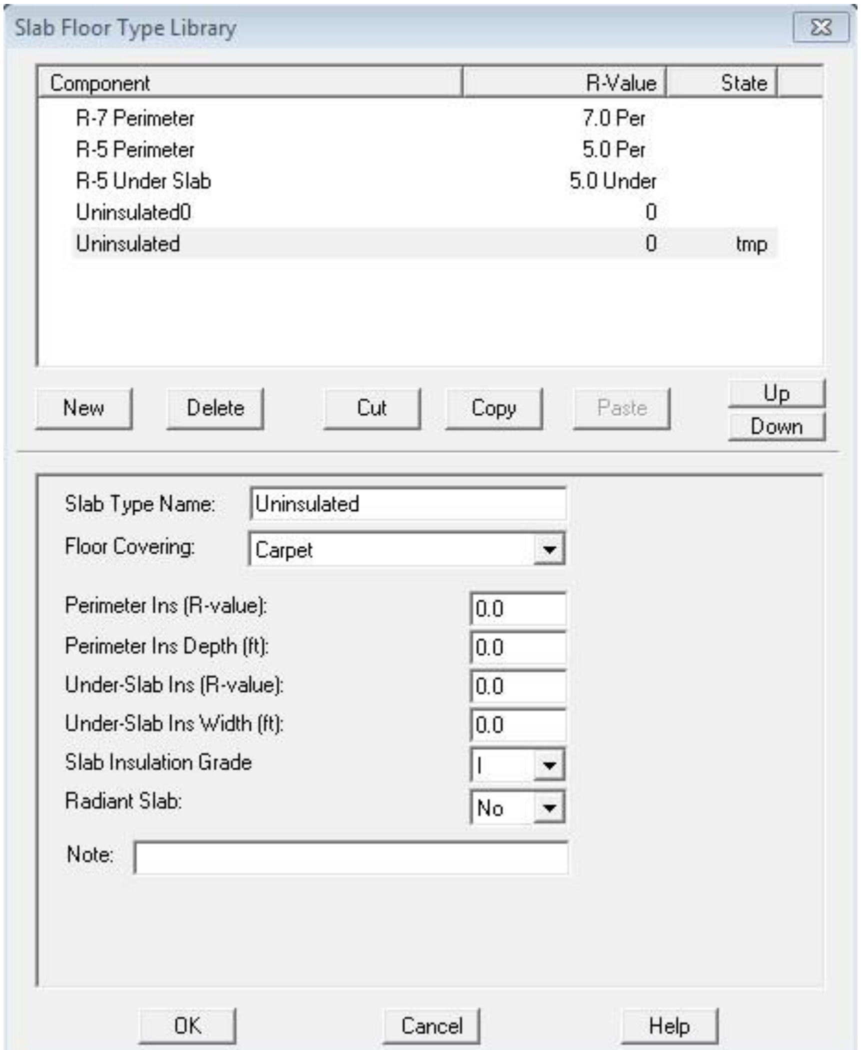


Figure C-4 shows the screenshot of the REM/Rate input details for the slab floors information. The inputs include the perimeter insulation, the perimeter insulation depth, the under slab insulation, the slab insulation grade, and the choice of radiant slab. This study set inputs for this model: R-0 for the perimeter insulation, 0 ft for the perimeter insulation depth, R-0 for the under slab insulation, 0 ft for the under slab insulation width, the slab insulation grade[14] I, and no radiant slab.

[14] Grade I shall be used to describe insulation that is generally installed according to manufacturer's instructions and/or industry standards. A "Grade I" installation requires that the insulation material uniformly fills each side-to-side and top-to-bottom, without substantial gaps or voids around obstructions (such as blocking or bridging), and is split, installed, and/or fitted tightly around wiring and other services (AEC, 2013).

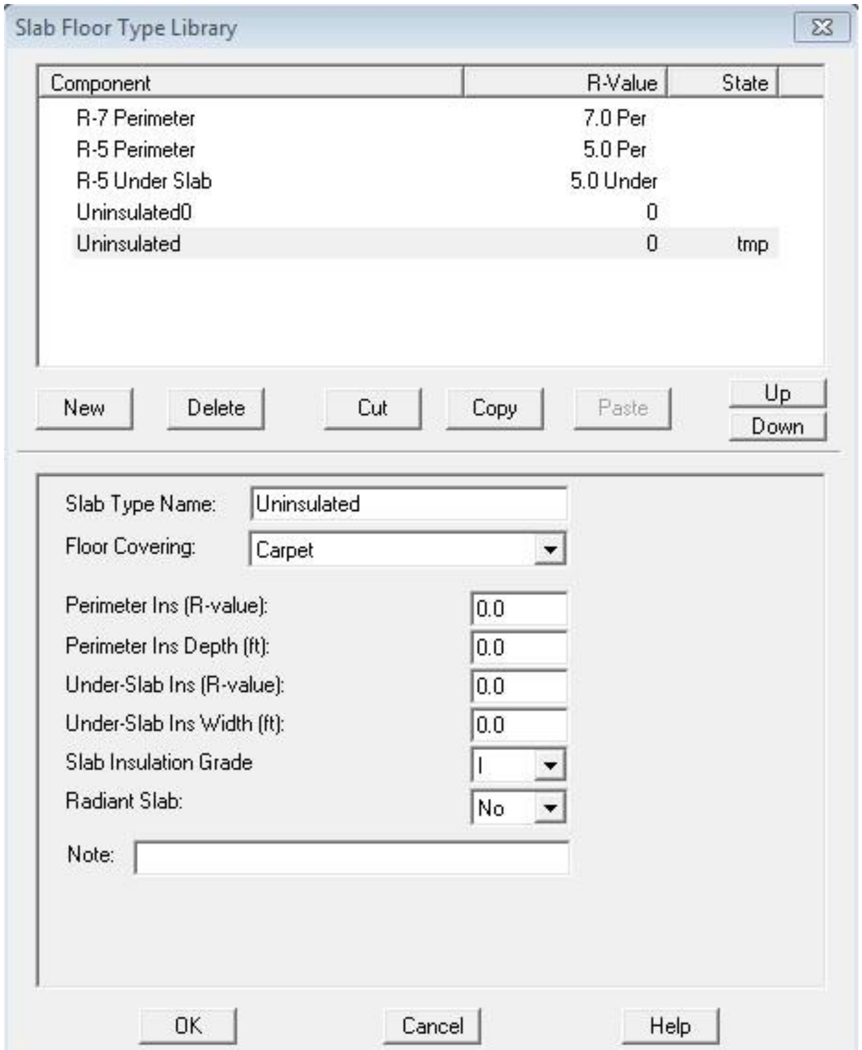


Figure C-4: Screenshot of REM/Rate Input for Slab Floor Detail

Figure C-5 shows the screenshot of the REM/Rate input for the above-grade walls. The inputs include the gross area, the exterior color, and the wall location. This study constructed 400 ft^2 for the gross area wall on each side, set the medium[15] for the exterior color, and located the walls between conditioned space and ambient space.

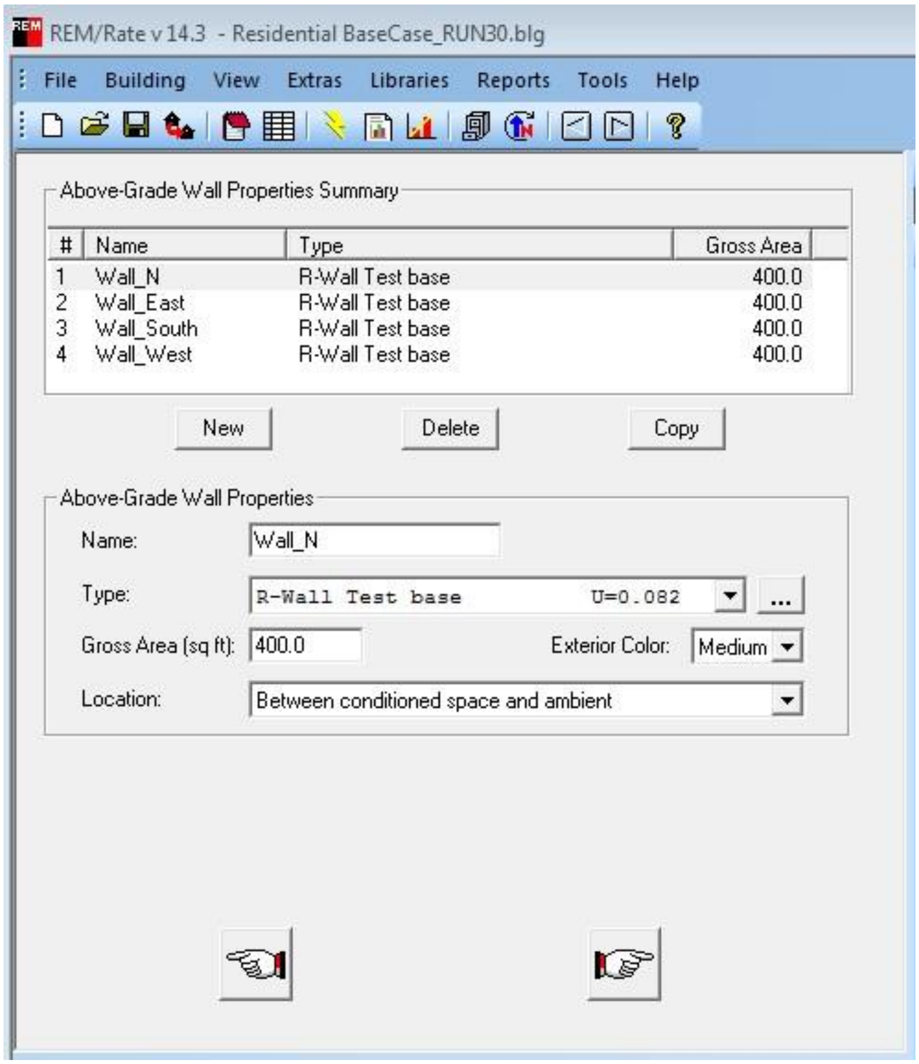


Figure C-5: Screenshot of REM/Rate Input for Above-Grade Wall

[15] Medium of the exterior color represents 0.75 of the wall absorptivity.

Figure C-6 shows the screenshot of the REM/Rate input for the details of above-grade walls. Exterior above-grade walls were composed of gypsum board, insulation (i.e., the cavity part) or stud (i.e., the stud part), plywood, air-layer, and brick exterior finish. In addition, this study set 75% of the exterior wall area composed for the cavity part and 25% for the exterior wall area composed of the stud part.

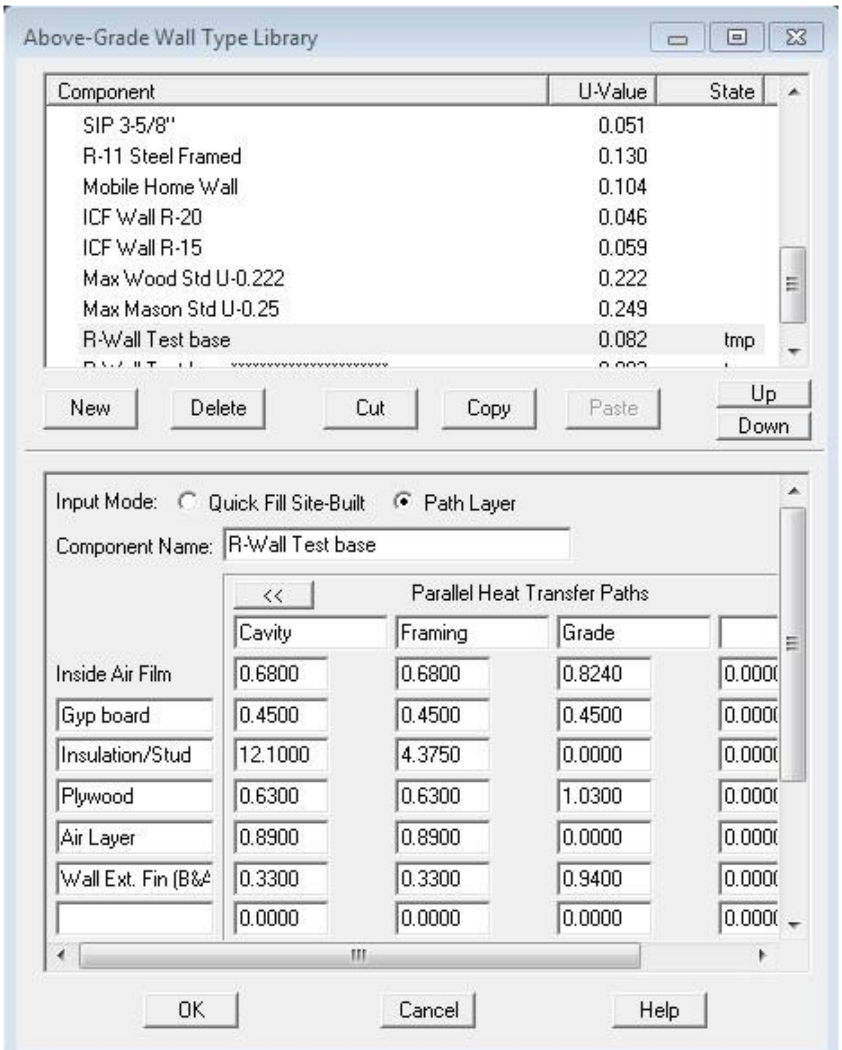


Figure C-6: Screenshot of REM/Rate Input for Above-Grade Wall Detail

Figure C-7 shows the screenshot of the REM/Rate input for the windows information. The inputs include information of the window area, orientation, overhang, interior shading, and adjacent shading. This study used 93.8 ft^2 for each window area, and attached one window on each exterior wall (i.e., total of four windows are used). In addition, this study set no overhang, 0.85 and 0.7 for interior shading for winter and summer, respectively, and no adjacent shading.

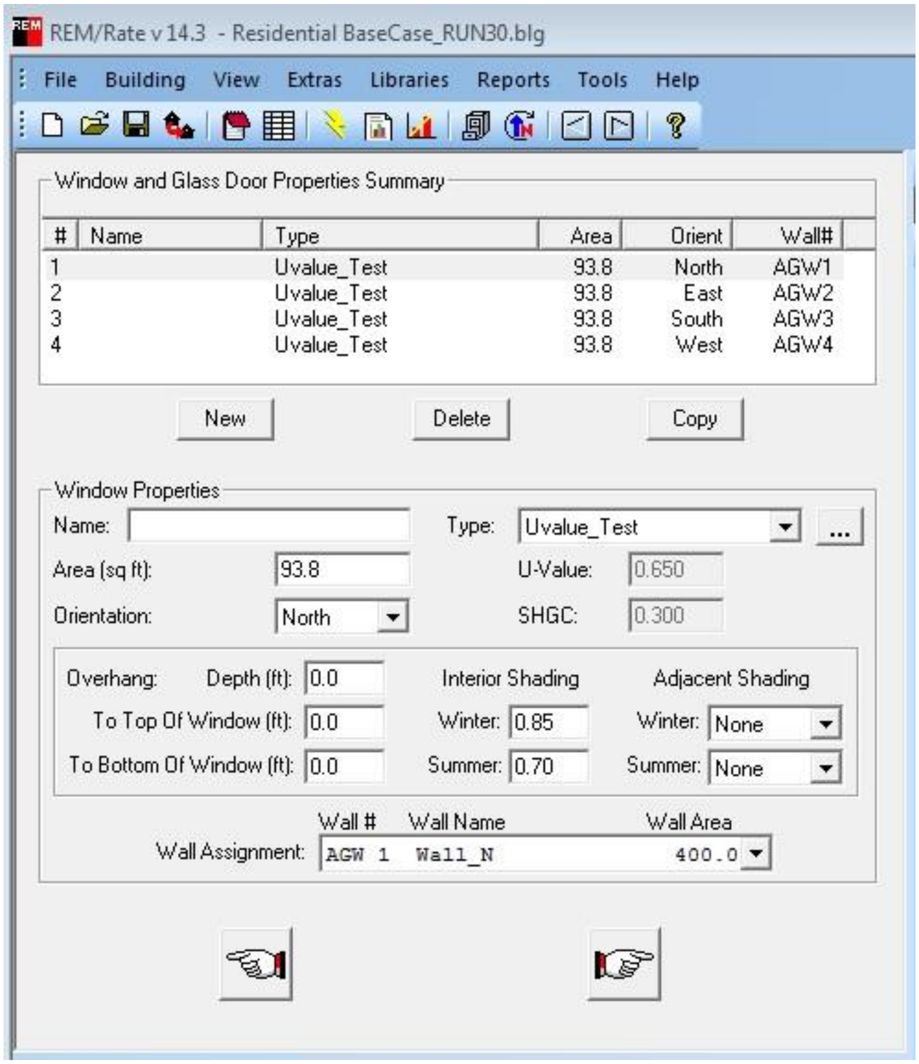


Figure C-7: Screenshot of REM/Rate Input for Windows and Glass Doors

Figure C-8 shows the screenshot of the REM/Rate input for the windows detail. This model set 0.65 for U-value and 0.3 for SHGC.

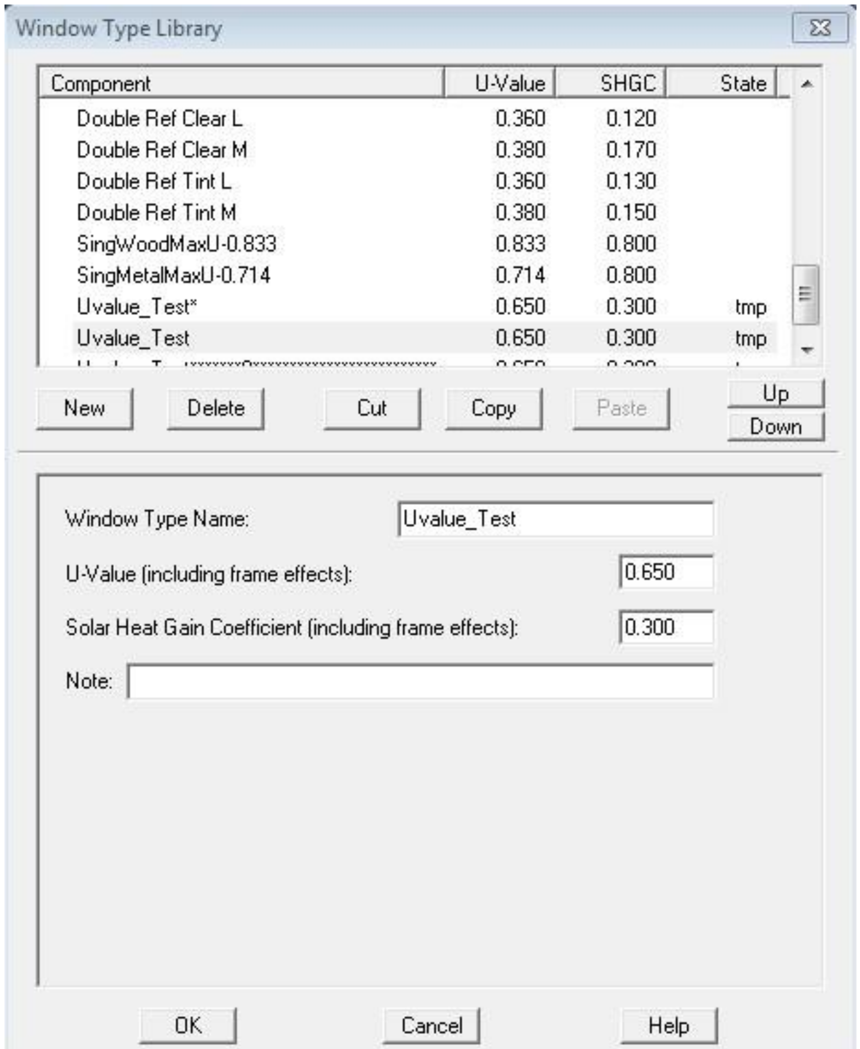


Figure C-8: Screenshot of REM/Rate Input for Window Detail

Figure C-9 shows the screenshot of the REM/Rate input for a door. The inputs include the door area and wall assignment. This study constructed a door on the North wall which has 40 ft^2 for the door area.

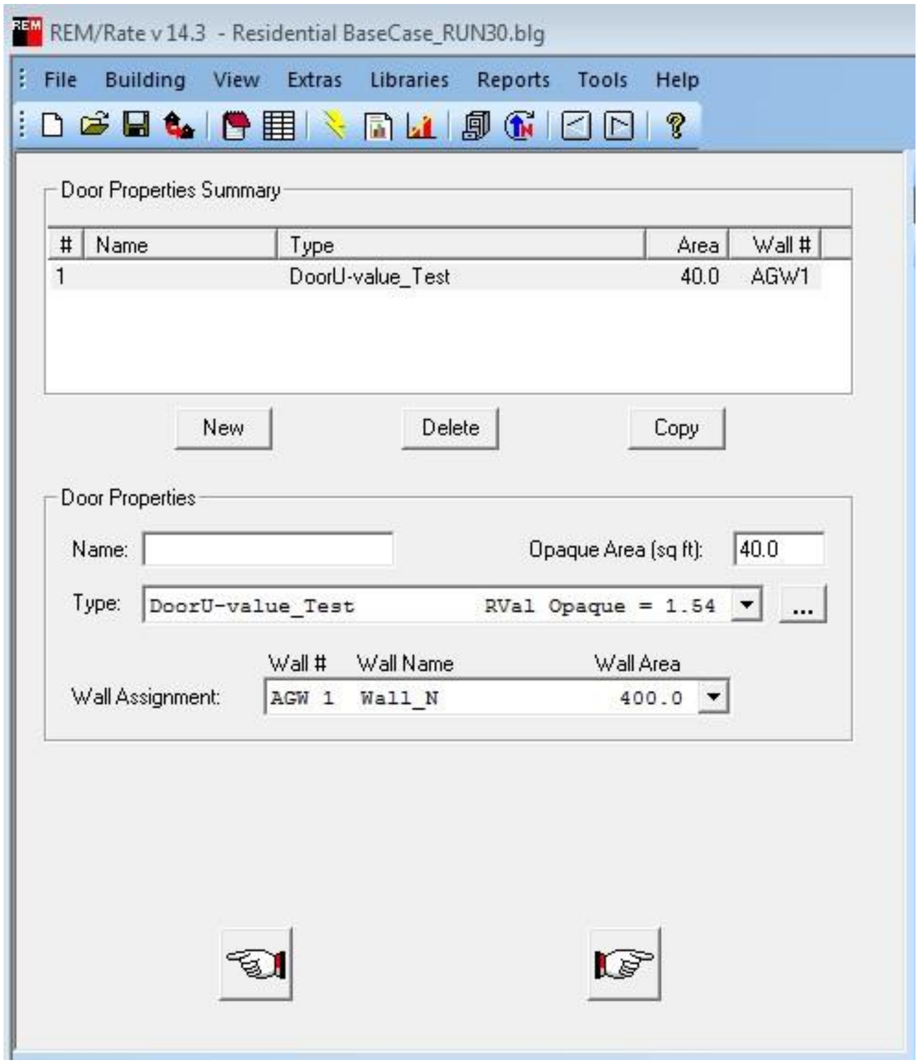


Figure C-9: Screenshot of REM/Rate Input for Door

Figure C-10 shows the screenshot of the door detail in REM/Rate. The inputs include the opaque door R-value and the storm door option. This study set R-1.54 for the door, which is equivalent to U-0.65. The door was not the storm door.

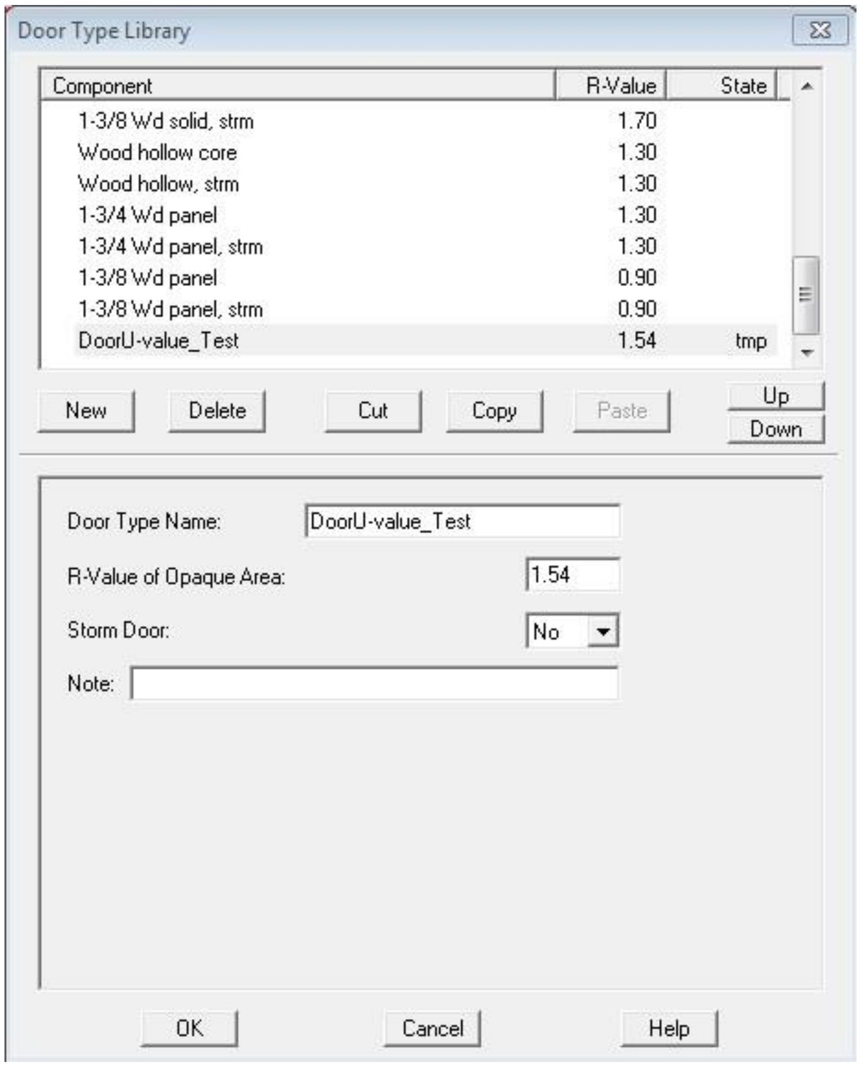


Figure C-10: Screenshot of REM/Rate Input for Door Detail

Figure C-11 shows the screenshot of the REM/Rate input for the ceiling information. The inputs include the ceiling area, the attic exterior area, and the roof property information which is optional inputs. This study set 2,500 ft^2 for both the ceiling area and the attic exterior area. The "Medium[16]" was used for the exterior roof color; the roofing tile, radiant barrier, and sub-tile ventilation were not used.

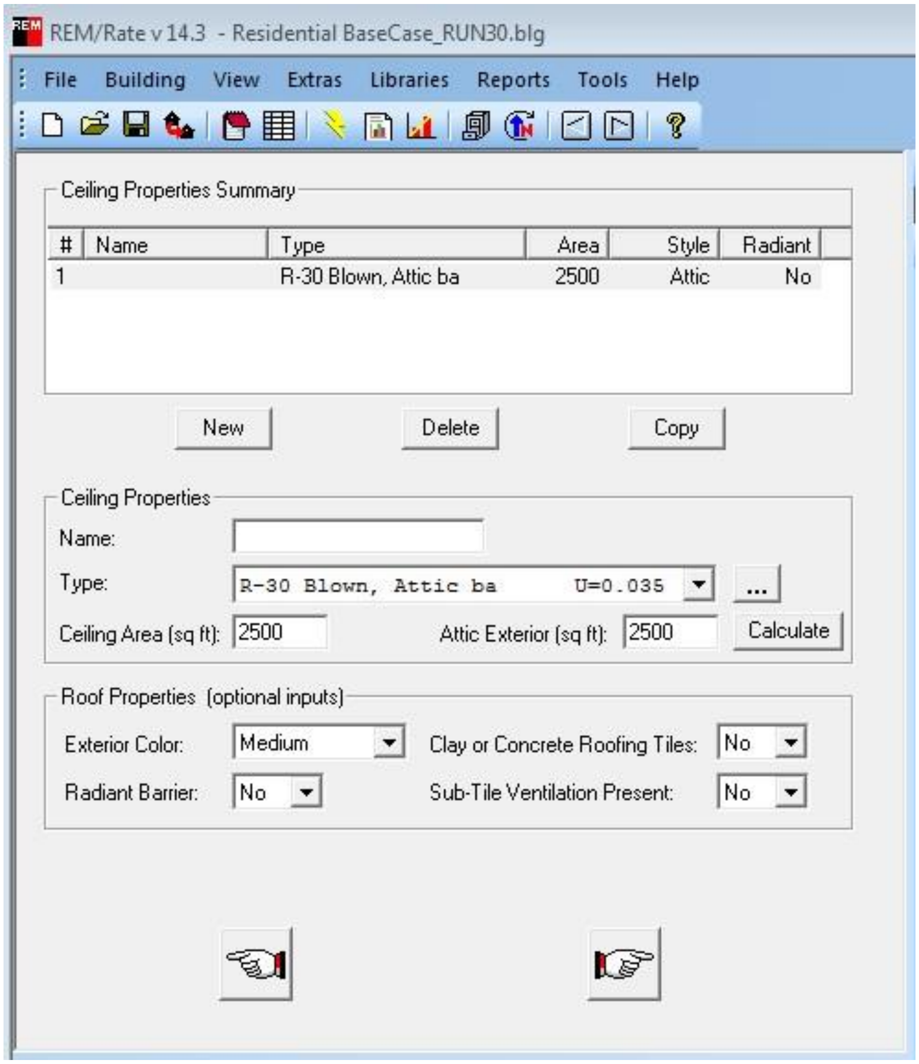


Figure C-11: Screenshot of REM/Rate Input for Ceiling

[16] Medium of the exterior color represents 0.75 of the wall absorptivity.

Figure C-12 shows the screenshot of the REM/Rate input for the ceiling details. Ceiling was composed of gypsum board, insulation (i.e., the cavity part) or stud (i.e., the stud part), and continuous insulation. In addition, this study set 93% for the exterior ceiling area composed of the cavity part and 7% for the exterior ceiling area composed of the stud part.

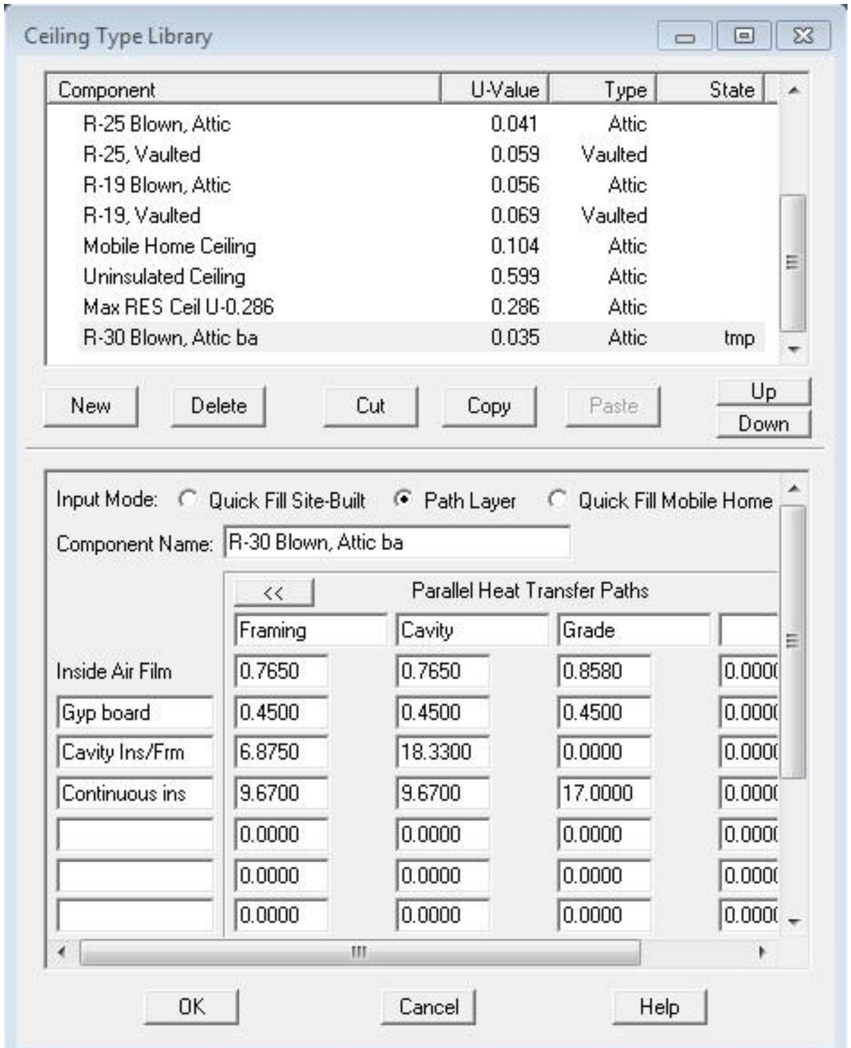


Figure C-12: Screenshot of REM/Rate Input for Ceiling Detail

Figure C-13 shows the screenshot of the REM/Rate input for the mechanical equipment. The inputs include the number of the HVAC units, the location, the percentage of the performance adjustment, and thermostat settings. The study defined an ASHP using space heating equipment and space cooling equipment, separately, and an electric water heater. 100% performance adjustment was used for each system type, and the thermostat was set at 72 °F for heating and 75°F for cooling.

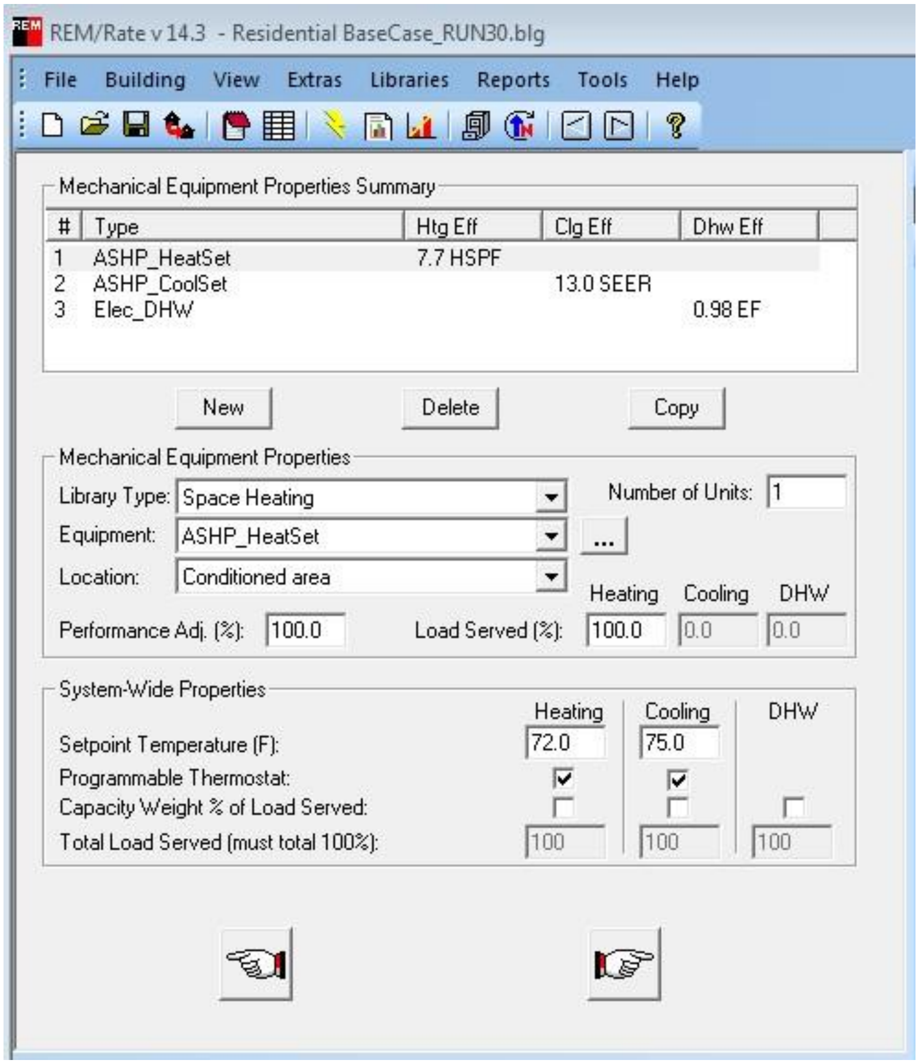


Figure C-13: Screenshot of REM/Rate Input for Mechanical Equipment

Figure C-14 shows the screenshot of the REM/Rate input for the details of heating equipment. The inputs include the heating system type, the fuel type, the rated capacity at 47 °F and 17 °F, the seasonal equipment efficiency (i.e., HSPF for the ASHP), and the auxiliary heat pump. This study used an electric ASHP and set system capacities as 60 kBtu/hr at 47 °F and 37 kBtu/hr at 17 °F. 7.7 HSPF was used for system efficiency and the default for the auxiliary input was used.

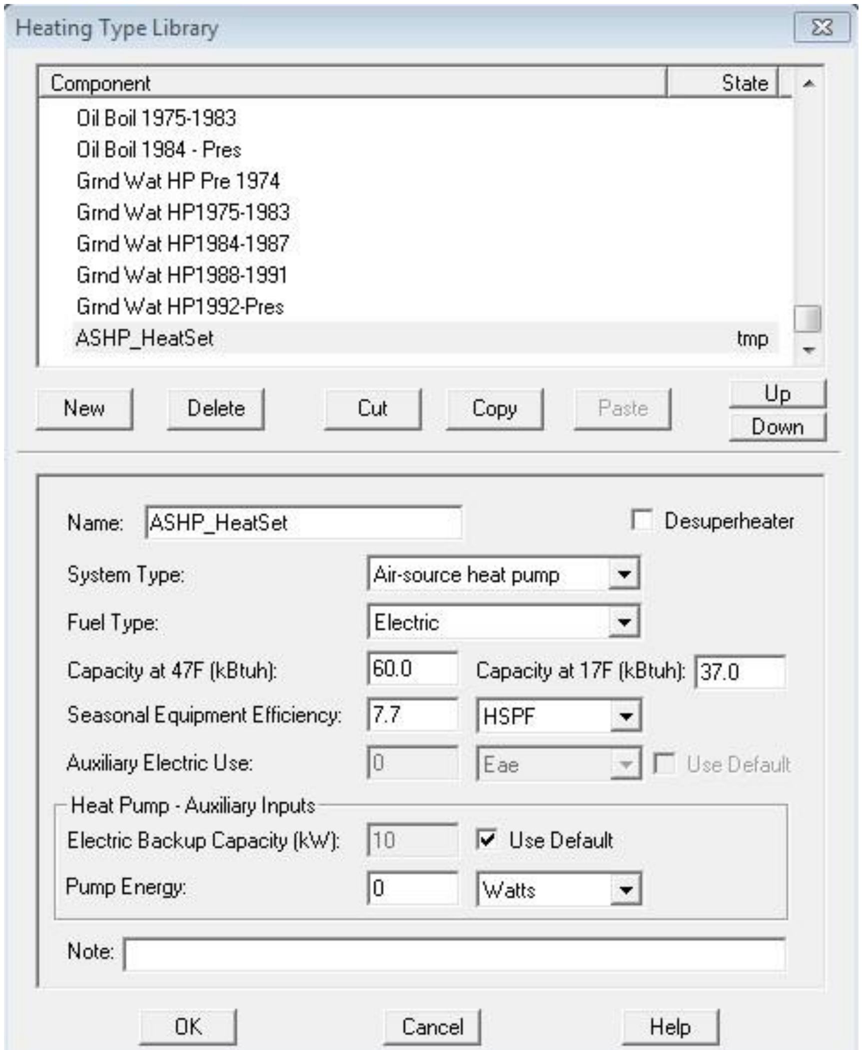


Figure C-14: Screenshot of REM/Rate Input for Heating Equipment Detail

Figure C-15 shows the screenshot of the REM/Rate input for the cooling equipment detail. The inputs include the cooling system type, the fuel type, the rated system capacity, the seasonal equipment efficiency (i.e., SEER for the ASHP), the sensible heat fraction, and auxiliary heat pump inputs. Likely the heating system, the ASHP system was used for the cooling system, which had 60 kBtuh of the system capacity. SEER 13 was used for the ASHP system efficiency; 0.69 for the sensible heat fraction and, this study assumed this system does not have any electric power consumption for the auxiliary fan and pump.

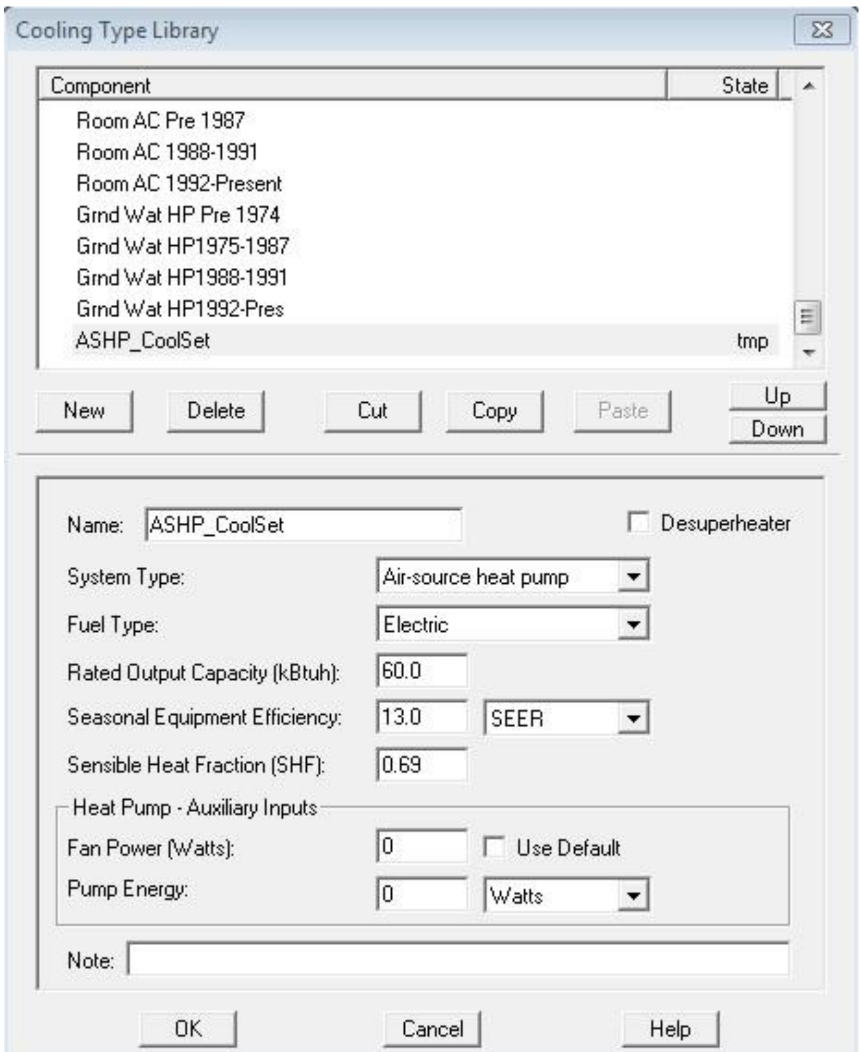


Figure C-15: Screenshot of REM/Rate Input for Cooling Equipment Detail

Figure C-16 shows the screenshot of the REM/Rate input for the water heater detail. The inputs include the water heater system, the fuel type, and the energy factor. The DHW system in this study was an electric water heater which has 0.98 for the energy factor[17].

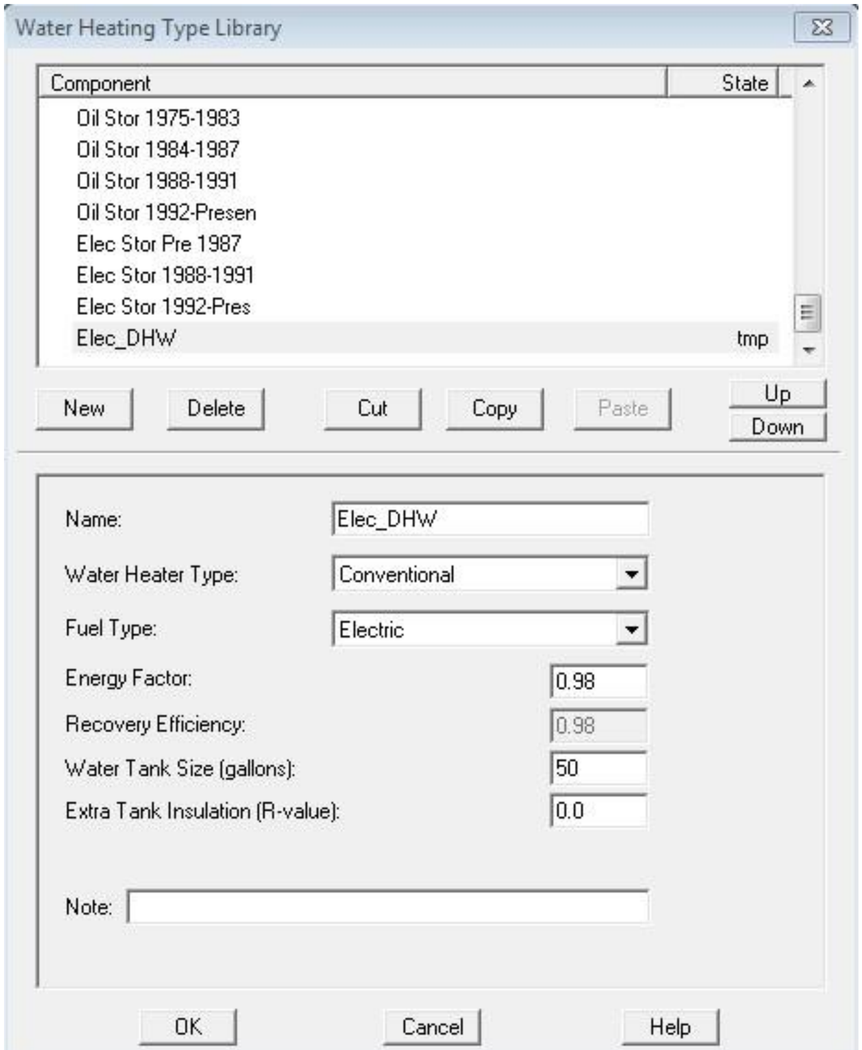


Figure C-16: Screenshot of REM/Rate Input for Water Heater Detail

[17] REM/Rate has the maximum limitation of the energy factor for a conventional electric water heater; the maximum EF is 0.98.

Figure C-17 shows the screenshot of the REM/Rate input for the duct system. The inputs include the duct system service area, the number of return grill, the duct surface area, the duct leakage, the total duct leakage, and the duct location. This study set 2,500 ft^2 for the duct service area with one return grill. The supply duct area was set as 675 ft^2 and the return duct area was set as 125 ft^2. This study assumed the duct does not have any leakage since the duct system is located in the conditioned space.

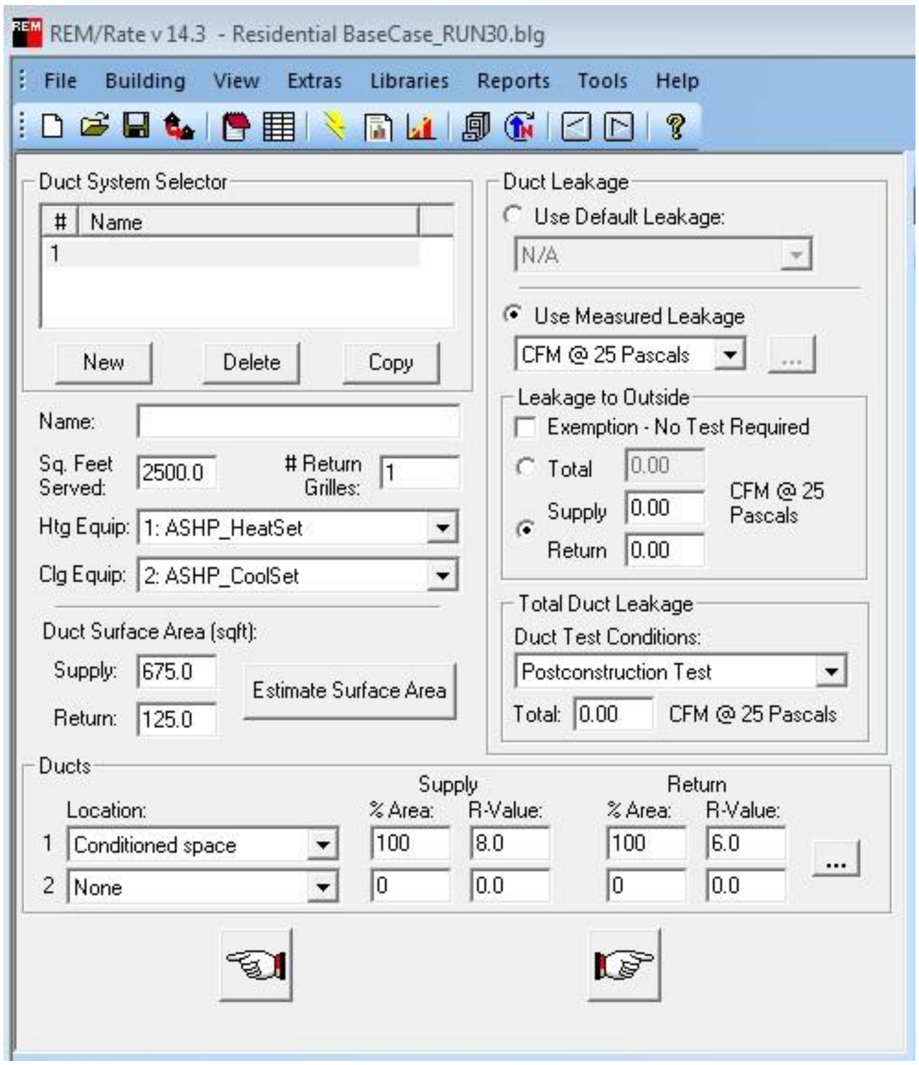


Figure C-17: Screenshot of REM/Rate Input for Duct System

Figure C-18 shows the screenshot of the REM/Rate input for infiltration. The inputs include the infiltration measurement type, infiltration values, the shelter class, 2009 IECC verification, and mechanical ventilation. This study set the code default for the measurement type with 0.00043 for the specific leakage area for both the heating season and the cooling season. The shelter class was set as 3[18] , which is corresponding to 0.24 for the shielding-coefficient used in DOE-2.1e. 2009 IECC verification was set as "Tested". The model in this study does not use any mechanical ventilation.

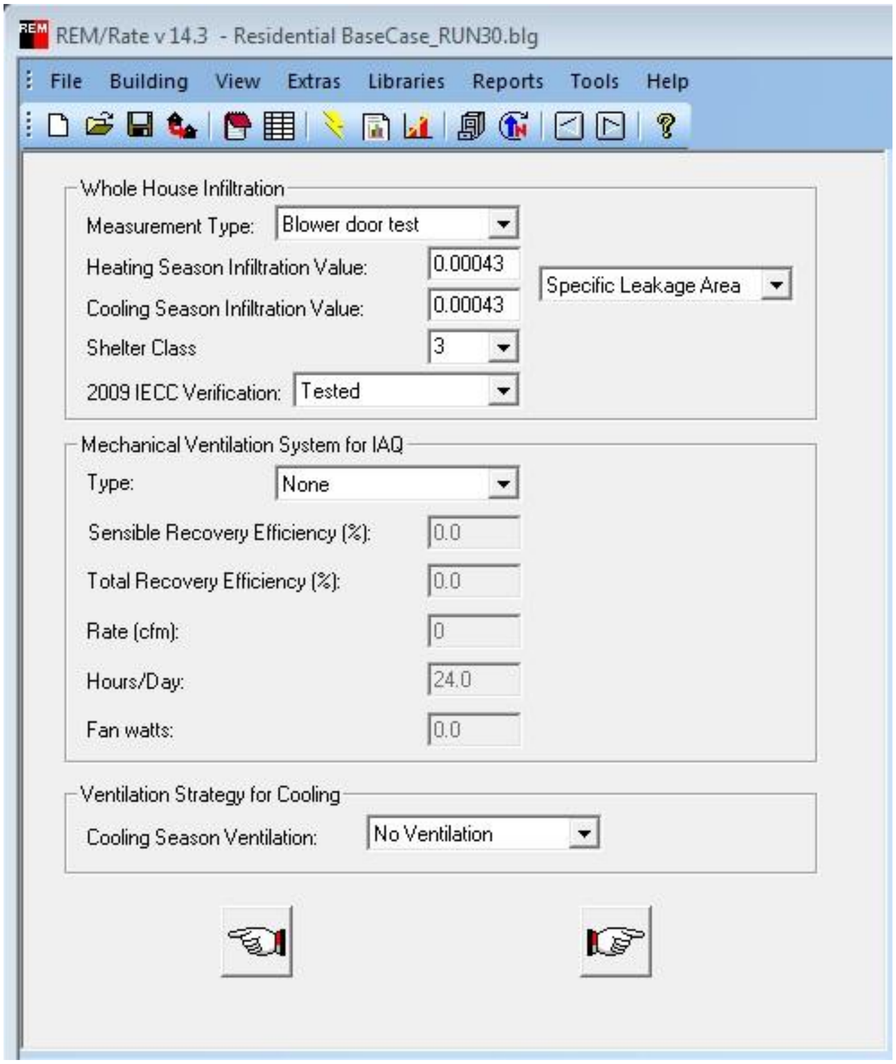


Figure C-18: Screenshot of REM/Rate Input for Infiltration

[18] Shelter class represents the effect of a home's surroundings on the wind pressures seen by the home. 3 of the shelter class represents the moderate local shielding.

Figure C-19 shows the screenshot of the REM/Rate input for the lighting & equipment. The inputs include lighting, appliance, and hot water usage. Total electric power for the lighting fixtures was set as 489 watts per hour, using a whole day. Total electric power for plug load, which represents the equipment usage in the RUN_30 base-case model, was set as 658 watts per hour, using a whole day. The study set 70 gallon for hot water for a day.

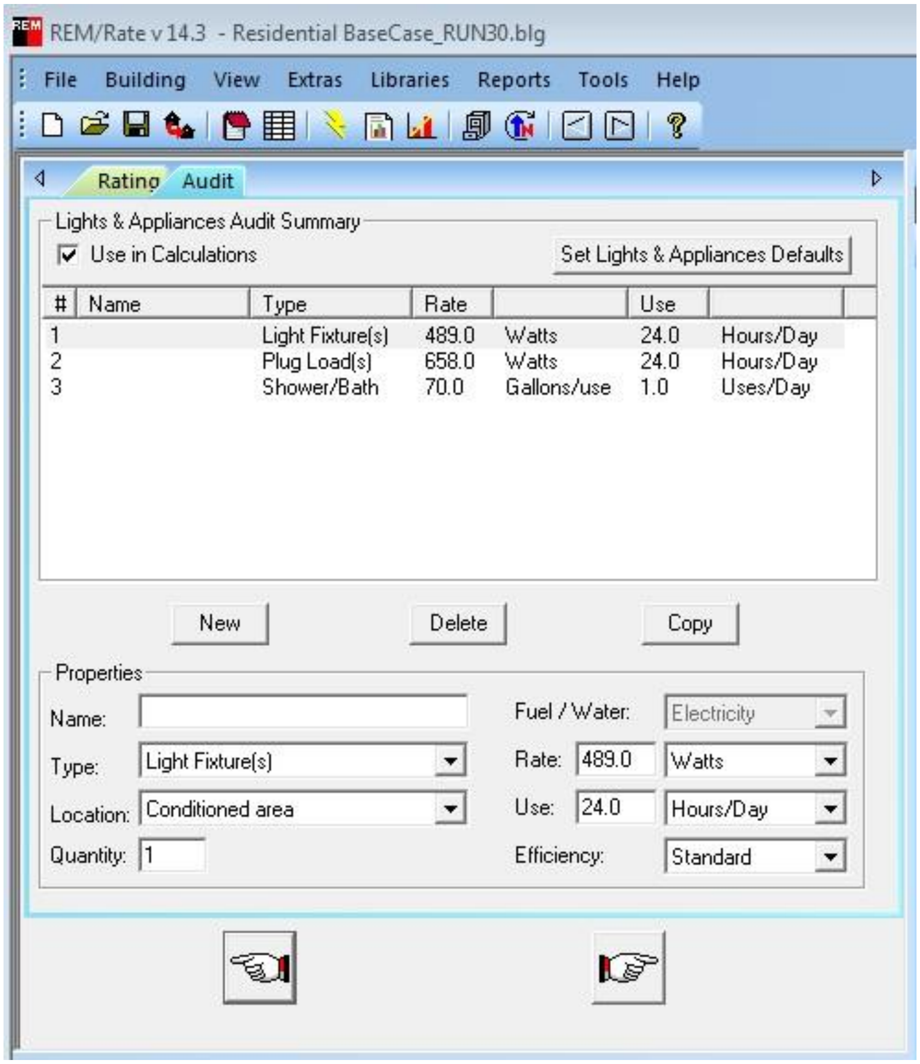


Figure C-19: Screenshot of REM/Rate Input for Lighting & Equipment

Appendix D: DOE-2.1e BDL Input for RUN_30

The procedure to develop the simplified residential base-case model with an ASHP system consists of six categories, including categories of the *Project*, the *ASHP System*, the *Construction*, the *Internal Gain*, the *Schedule*, and the *DHW*. Using the development procedure, RUN_30, which is the final simulation name, represents the simplified residential base-case model. The DOE-2.1e BDL input for RUN_30 is presented in this appendix, as follows:

```
$*******************************************************************************
$    PROGRAM:         DOE-2 SIMULATION INPUT FILE                              *
$                                                                              *
$    LANGUAGE:        DOE-2.1E BDL VERSION 119                                 *
$                                                                              *
$    COPYRIGHT:       TEES, 2013.                                              *
$                     This program bears a copyright notice to prevent rights  *
$                     from being claimed by any other party. This program      *
$                     shall not be redistributed or sold without written       *
$                     approval from the Texas Engineering Experiment Station   *
$                     (TEES).                                                  *
$                                                                              *
$                     The program is distributed "as is". TEES DOES NOT        *
$                     WARRANT THAT THE OPERATION OF THE PROGRAM WILL BE        *
$                     UNINTERRUPTED OR ERROR-FREE, AND MAKES NO                *
$                     REPRESENTATIONS OR OTHER WARRANTIES, EXPRESS OR IMPLIED, *
$                     INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES      *
$                     OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. *
$                                                                              *
$                     No support service will be provided unless              *
$                     written arrangements have been made to do so. Certain    *
$                     manufacturers and trade names are mentioned in this code *
$                     for the purpose of describing  their product parameters  *
$                     Such reference does not constitute an                    *
$                     endorsement or recommendation of such equipment, but is  *
$                     provided for informational purposes only.                *
$                                                                              *
$    DEVELOPER:       JEFF HABERL, Ph.D, P.E                                   *
$                     Professor                                                *
$                     Department of Architecture                               *
$                     Energy Systems Laboratory                                *
$                     Texas A&M University, College Station, TX                *
$                     PHONE: (979)845-6065                                     *
$                                                                              *
$    PROGRAMMERS:     SUNG LOK DO                                              *
$                     Ph.D. Student                                            *
$                     Department of Architecture                               *
$                     Energy Systems Laboratory                                *
$                     Texas A&M University, College Station, TX                *
$                                                                              *
$                     JONG-HYO CHOI                                            *
$                     M.S. Student                                             *
$                     Department of Architecture                               *
$                     Energy Systems Laboratory                                *
$                     Texas A&M University, College Station, TX                *
$                                                                              *
$*******************************************************************************

$ RUN_3A.INP - RUN_3A WITH HOUSTON LOCATION.
$ RUN_1.INP - REDUCE THE NUMBER OF SPACE FROM 5 TO 1.
$ RUN_2.INP - REDUCE AREA FROM 5,000 SQFT TO 2,500 SQFT and ADJUST FENESTRATION
$ RUN_3.INP - REMOVE FRONT DOOR OVERHANG
$ RUN_4.INP - ROTATE BUILDING TO SOUTH FACE
$ RUN_5.INP - CHANGE NUMBER OF PEOPLE, FROM 52 TO 0
$ RUN_6.INP - REMOVE PLENUM AND RETURN-AIR-PATH FROM PLENUM TO DIRECT
$ RUN_7.INP - MERGE FROM TWO DOORS FACING SOUTH AND NORTH TO SINGLE DOOR FACING NORTH
$ RUN_8.INP - CHANGE SYSTEM FROM VAVS TO RESYS
$ RUN_9.INP - COOLING EIR, 13 SEER
$ RUN_10.INP - HEATING EIR, 7.7 HSPF
$ RUN_11.INP - SYSTEM FAN SCHEDULE SET TO 1 FOR ALL HOURS
$ RUN_12.INP - SYSTEM HEAT SCHEDULE SET TO 72 FOR ALL HOURS
$ RUN_13.INP - SYSTEM COOL SCHEDULE SET TO 75 FOR ALL HOURS
$ RUN_14.INP - SET SUPPLY AIR FLOW 360 CFM/TON (500 SQFT/TON)
$ RUN_15.INP - CLIMATE ZONE2 CODE REQUIREMENT FOR SLAB-ON-GRADE FLOOR, R-0
$ RUN_16.INP - CLIMATE ZONE2 CODE REQUIREMENT FOR ROOF, U-0.035
$ RUN_17.INP - CLIMATE ZONE2 CODE REQUIREMENT FOR ROOF, ABSORPTANCE 0.75
$ RUN_18.INP - CLIMATE ZONE2 CODE REQUIREMENT FOR WALL, U-0.082
$ RUN_19.INP - CLIMATE ZONE2 CODE REQUIREMENT FOR WALL, ABSORPTANCE 0.75
$ RUN_20.INP - CLIMATE ZONE2 CODE REQUIREMENT FOR DOOR, U- 0.65
$ RUN_21.INP - CLIMATE ZONE2 CODE REQUIREMENT FOR WINDOW, U- 0.65, SHGC, 0.3, w/ Frame
$ RUN_22.INP - INFILTRATION, ACH = 0.35
$ RUN_23.INP - GROUND REFELCTANCE, GND-REFLECTANCE = 0.24
```

```
$ RUN_24.INP - LIGHTING POWER DENSITY TO 0.1951
$ RUN_25.INP - EQUIPMENT POWER DENSITY TO 0.2632
$ RUN_26.INP - LIGHTING SCHEDULES SET TO 1 FOR ALL HOURS
$ RUN_27.INP - EQUIPMENT SCHEDULES SET TO 1 FOR ALL HOURS
$ RUN_28.INP - INFILTRATION SCHEDULES SET TO 1 FOR ALL HOURS
$ RUN_29.INP - INTERIOR SHADING SCHEDULES
$ RUN_30.INP - ELEC DHW INSTALLATION

$               ----------------------------------------------------
$              ! !                                                 ! !
$              !   !                 SPACE 3-1                   !   !
$              !     !                                         !     !
$              !        !---------------------------------- !        !
$              !         !                                 !         !
$              !         !                                 !         !
$              !         !                                 !         !
$              !         !                                 !         !
$              !SPACE4-1 !            SPACE5-1             !SPACE2-1 !
$              !         !                                 !         !
$              !         !            (RUN_3A)             !         !
$              !         !                                 !         !
$              !         !                                 !         !
$              !       !  --------------------------------- !        !
$              !     !                                         !     !
$              !   !                 SPACE 1-1                   !   !
$              ! !                                                 ! !
$               ----------------------------------------------------

$                         ----------------------------------
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                        !             SPACE1-1             !
$                        !                                  !
$                        !             (RUN_30)             !
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                        !                                  !
$                         ----------------------------------


INPUT LOADS     ..

TITLE           LINE-1 *SIMPLIFIED RESIDENTIAL BASE-CASE MODEL*
                LINE-2 *HOUSTON, TX*
                LINE-3 *USING IECC CODE REQUIREMENTS*
                LINE-4 *DEVELOPED BY SUNG LOK DO AND JONG-HYO CHOI*
                LINE-5 *JUL 22 2013* ..

                RUN-PERIOD         JAN 1 2012 THRU DEC 31 2012       ..

                ABORT              ERRORS  ..
                DIAGNOSTIC         DEFAULTS ..
                LOADS-REPORT       SUMMARY = (ALL-SUMMARY)
                                   VERIFICATION = (ALL-VERIFICATION) ..

                BUILDING-LOCATION  LATITUDE       = 29.5                       $ FOR HOUSTON, TX
                                   LONGITUDE      = 95
                                   ALTITUDE       = 68
                                   TIME-ZONE      = 6
                                   AZIMUTH        = 0
                                   SHIELDING-COEF = 0.24 ..


$  BUILDING DESCRIPTION

$======================================== CONSTRUCTION ===========================================

$  CONSTRUCTION AND GLASS-TYPES

$  MATERIAL
ROOF_STUD      = MAT                THICKNESS = 0.4583                         $ 3.5" SOFT WOOD, MODIFIED
                                    CONDUCTIVITY = 0.0667
                                    DENSITY = 32
                                    SPECIFIC-HEAT = 0.33  ..
BATT-ACEIL     = MAT                THICKNESS = 0.696                          $ IN01-MODIFIED, CEILING INSULATION BELOW FLOOR
STUDS
                                    CONDUCTIVITY = 0.025
                                    DENSITY = 6
                                    SPECIFIC-HEAT = 0.2   ..
BATT-BCEIL     = MAT                THICKNESS = 0.23767                        $ IN01-MODIFIED, CEILING INSULATION ABOVE STUDS
                                    CONDUCTIVITY = 0.025
                                    DENSITY = 6
                                    SPECIFIC-HEAT = 0.2   ..

WALL_STUD      = MAT                THICKNESS = 0.2917                         $ 3.5" SOFT WOOD, MODIFIED
                                    CONDUCTIVITY = 0.0667
```

```
                                    DENSITY = 32
                                    SPECIFIC-HEAT = 0.33  ..
WALL_BATT      = MAT                THICKNESS = 0.295                      $ 2.25" MINERAL WOOL/FIBER, MODIFIED
                                    CONDUCTIVITY = 0.025
                                    DENSITY = 6
                                    SPECIFIC-HEAT = 0.2   ..

$  LAYERS
CLA_1          = LAYERS             MAT = (BATT-ACEIL,GP02)
                                    INSIDE-FILM-RES = 0.765   ..
CLA_2          = LAYERS             MAT = (BATT-BCEIL,ROOF_STUD,GP01)
                                    INSIDE-FILM-RES = 0.765   ..

WALL-1-1       = LAYERS             MAT = (BK04,AL21,PW03,WALL_BATT,GP01)
                                    INSIDE-FILM-RES = 0.68     ..
WALL-1-2       = LAYERS             MAT = (BK04,AL21,PW03,WALL_STUD,GP01)
                                    INSIDE-FILM-RES = 0.68    ..

$  CONSTRUCTION
CLNG-1         = CONSTRUCTION       LAYERS = CLA_1
                                    ABSORPTANCE = 0.75
                                    ROUGHNESS = 1         ..
CLNG-2         = CONSTRUCTION       LAYERS = CLA_2
                                    ABSORPTANCE = 0.75
                                    ROUGHNESS = 1         ..

WALL-1         = CONSTRUCTION       LAYERS = WALL-1-1
                                    ABSORPTANCE = 0.75
                                    ROUGHNESS = 2         ..
WALL-2         = CONSTRUCTION       LAYERS = WALL-1-2
                                    ABSORPTANCE = 0.75
                                    ROUGHNESS = 2         ..

$  SLAB-ON-GRADE
MAT-FIC-1      = MAT                RESISTANCE = 7.5436   ..               $ UNDERGROUND FLOOR
SOIL-12IN      = MAT                THICKNESS = 1                          $ UNDERGROUND SURFACE
                                    CONDUCTIVITY = 1
                                    DENSITY = 115
                                    SPECIFIC-HEAT = 0.1   ..
CPXX           = MAT                RESISTANCE = 1.61     ..               $ CARPET + TILE
LAY-SLAB-1     = LAYERS             MATERIAL = (MAT-FIC-1,SOIL-12IN,CC03,CPXX)
                                    INSIDE-FILM-RES = 0.765   ..

CON-SLAB-1     = CONSTRUCTION       LAYERS = LAY-SLAB-1   ..

$  FENESTRATION
W-1            = GLASS-TYPE         GLASS-CONDUCTANCE = 0.3823
                                    SHADING-COEF = 0.426
                                    FRAME-CONDUCTANCE = 3.037
                                    PANES = 1                     ..

DOORS          = CONSTRUCTION       U = 0.65  ..                           $ TABLE 402.1.3 IN 2009 IECC

$==================================== SCHEDULES ==============================================

$ OCCUPANCY SCHEDULE
OCCUPY-1      = SCHEDULE            THRU DEC 31 (ALL) (1,24) (1)       ..      $ SET TO CONSTANT

$ LIGHTING SCHEDULE
LIGHTS-1      = SCHEDULE            THRU DEC 31 (ALL) (1,24) (1)       ..      $ SET TO CONSTANT

$ EQUIPMENT SCHEDULE
EQUIP-1       = SCHEDULE            THRU DEC 31 (ALL) (1,24) (1)       ..      $ SET TO CONSTANT

$ INFILTRATION SCHEDULE
INFIL-SCH     = SCHEDULE            THRU DEC 31 (ALL) (1,24) (1)       ..      $ SET TO CONSTANT

$ INTERIOR SHADING SCHEDULE
SH-1          = SCHEDULE
                                    THRU APR 30 (ALL) (1,24)  (0.85)
                                    THRU OCT 31 (ALL) (1,24)  (0.7)
                                    THRU DEC 31 (ALL) (1,24)  (0.85)   ..      $ TABLE 405.5.2(1) IN 2009 IECC

$=============================== SPACE DEFAULTS & DESCRIPTION =================================

$ SET DEFAULT VALUES

                SET-DEFAULT FOR SPACE          FLOOR-WEIGHT = 0       ..       $ CUSTOM WEIGHTING FACTOR
                SET-DEFAULT FOR EXTERIOR-WALL  GND-REFLECTANCE = 0.24 ..
                SET-DEFAULT FOR ROOF           GND-REFLECTANCE = 0.24 ..
                SET-DEFAULT FOR WINDOW         HEIGHT= 4.222
                                               GLASS-TYPE = W-1
                                               Y = 2                  ..

$ GENERAL SPACE DEFINITION

OFFICE         = SPACE-CONDITIONS  PEOPLE-SCHEDULE     = OCCUPY-1
                                   NUMBER-OF-PEOPLE    = 0                 $ PEOPLE REMOVED
                                   PEOPLE-HEAT-GAIN    = 400               $ ASHRAE HANDBOOK OF FUNDAMENTALS 2001 CHAPTER 29
                                   LIGHTING-SCHEDULE   = LIGHTS-1
                                   LIGHTING-TYPE       = REC-FLUOR-RV
                                   LIGHT-TO-SPACE      = 0.8               $ DOE-2 DEFAULT FOR REC-FLUOR-RV
                                   LIGHTING-W/SQFT     = 0.1951            $ TABLE 405.5.2(1) IN 2009 IECC
                                   EQUIP-SCHEDULE      = EQUIP-1
                                   EQUIPMENT-W/SQFT    = 0.2632            $ TABLE 405.5.2(1) IN 2009 IECC
```

```
                                   INF-METHOD          = S-G                    $ SHERMAN-GRIMSRUD INFILTRATION METHOD
                                   FRAC-LEAK-AREA      = 0.0004321              $ ACH = SLA X 1,000 X W X NS^0.3, w=0.81 & NS=1
                                   HOR-LEAK-FRAC       = 0.4                    $ DOE-2 DEFAULT
                                   NEUTRAL-LEVEL       = 0.5                    $ DOE-2 DEFAULT
                                   INF-SCHEDULE        = INFIL-SCH    ..

$================================ SPACE DETAILS ================================================
$ SPECIFIC SPACE DETAILS

SPACE1-1      = SPACE              SPACE-CONDITIONS = OFFICE
                                   AREA = 2500
                                   VOLUME = 20000             ..

    FRONT-1    = EXTERIOR-WALL     HEIGHT = 8
                                   WIDTH = 8.95
                                   X = 0
                                   Y = 0
                                   Z = 0
                                   AZIMUTH = 180
                                   CONSTRUCTION = WALL-2       ..

    FRONT-2    = EXTERIOR-WALL     HEIGHT = 8
                                   WIDTH = 41.05
                                   X = 8.95
                                   Y = 0
                                   Z = 0
                                   AZIMUTH = 180
                                   CONSTRUCTION = WALL-1       ..

      WF-1     = WINDOW            WIDTH = 17.972
                                   X = 3.125
                                   FRAME-WIDTH = 0.389
                                   SHADING-SCHEDULE = SH-1     ..

    RIGHT-1    = EXTERIOR-WALL     HEIGHT = 8
                                   WIDTH = 9.57
                                   X = 50
                                   Y = 0
                                   Z = 0
                                   AZIMUTH = 90
                                   CONSTRUCTION = WALL-2    ..

    RIGHT-2    = EXTERIOR-WALL     HEIGHT = 8
                                   WIDTH = 40.43
                                   X = 50
                                   Y = 9.57
                                   Z = 0
                                   AZIMUTH = 90
                                   CONSTRUCTION = WALL-1       ..

      WR-1     = WINDOW            WIDTH = 17.972
                                   X = 3.125
                                   FRAME-WIDTH = 0.389
                                   SHADING-SCHEDULE = SH-1     ..

    BACK-1     = EXTERIOR-WALL     HEIGHT = 8
                                   WIDTH = 8.95
                                   X = 50
                                   Y = 50
                                   Z = 0
                                   AZIMUTH = 0
                                   CONSTRUCTION = WALL-2       ..

    BACK-2     = EXTERIOR-WALL     HEIGHT = 8
                                   WIDTH = 41.05
                                   X = 41.05
                                   Y = 50
                                   Z = 0
                                   AZIMUTH = 0
                                   CONSTRUCTION = WALL-1       ..

      WB-1     = WINDOW            WIDTH = 17.972
                                   X = 3.125
                                   FRAME-WIDTH = 0.389
                                   SHADING-SCHEDULE = SH-1     ..

      DB-1     = DOOR              WIDTH = 6
                                   HEIGHT = 6.67
                                   X = 32
                                   Y = 0
                                   CONSTRUCTION = DOORS        ..

    LEFT-1     = EXTERIOR-WALL     HEIGHT = 8
                                   WIDTH = 9.57
                                   X = 0
                                   Y = 50
                                   Z = 0
                                   AZIMUTH = 270
                                   CONSTRUCTION = WALL-2       ..

    LEFT-2     = EXTERIOR-WALL     HEIGHT = 8
                                   WIDTH = 40.43
                                   X = 0
                                   Y = 40.43
                                   Z = 0
```

```
                                  AZIMUTH = 270
                                  CONSTRUCTION = WALL-1        ..

      WL-1     = WINDOW           WIDTH = 17.972
                                  X = 3.125
                                  FRAME-WIDTH = 0.389
                                  SHADING-SCHEDULE = SH-1      ..


    F1-1       = UNDERGROUND-FLOOR AREA = 2500
                                  CONSTRUCTION = CON-SLAB-1
                                  INSIDE-VIS-REFL = 0.2
                                  INSIDE-SOL-ABS = 0.8         ..

    CEILING-1  = ROOF             HEIGHT = 50
                                  WIDTH = 46.5
                                  X = 3.5
                                  Y = 0
                                  Z = 8
                                  AZIMUTH = 180
                                  TILT = 0
                                  CONSTRUCTION = CLNG-1        ..

    CEILING-2  = ROOF             HEIGHT = 50
                                  WIDTH = 3.5
                                  X = 0
                                  Y = 0
                                  Z = 8
                                  AZIMUTH = 180
                                  TILT = 0
                                  CONSTRUCTION = CLNG-2        ..

END  ..

COMPUTE  LOADS   ..

$================================== SYSTEM DETAILS ===========================================

INPUT SYSTEMS   ..

               SYSTEMS-REPORT  SUMMARY = (ALL-SUMMARY)  ..

$================================== SYSTEM SCHEDULES =========================================

$ SYSTEMS SCHEDULES

FAN-SCHED   = SCHEDULE        THRU DEC 31 (ALL) (1,24) (1)      ..    $ SET TO CONSTANT

HEAT-SCHED  = SCHEDULE        THRU DEC 31 (ALL) (1,24) (72)     ..    $ TABLE 405.5.2(1) IN 2009 IECC

COOL-SCHED  = SCHEDULE        THRU DEC 31 (ALL) (1,24) (75)     ..    $ TABLE 405.5.2(1) IN 2009 IECC

DHW-SCHED   = SCHEDULE        THRU DEC 31 (ALL) (1,24) (1)      ..    $ SET TO CONSTANT

DHWINLETSCH-1  = SCHEDULE     THRU JAN 31 (ALL) (1,24) (64.39)        $ DHW INLET TEMP SCHEDULE (HENDRON, 2004)
                              THRU FEB 28 (ALL) (1,24) (64.74)
                              THRU MAR 31 (ALL) (1,24) (67.52)
                              THRU APR 30 (ALL) (1,24) (72.02)
                              THRU MAY 31 (ALL) (1,24) (77.05)
                              THRU JUN 30 (ALL) (1,24) (81.3)
                              THRU JUL 31 (ALL) (1,24) (83.67)
                              THRU AUG 31 (ALL) (1,24) (83.54)
                              THRU SEP 30 (ALL) (1,24) (80.94)
                              THRU OCT 31 (ALL) (1,24) (76.55)
                              THRU NOV 30 (ALL) (1,24) (71.52)
                              THRU DEC 31 (ALL) (1,24) (67.15)   ..

$================================== SYSTEM DESCRIPTION =======================================

$ SYSTEM DESCRIPTION


CONTROL   = ZONE-CONTROL      DESIGN-HEAT-T    = 70                   $ DOE-2 DEFAULT
                              DESIGN-COOL-T    = 76                   $ DOE-2 DEFAULT
                              HEAT-TEMP-SCH    = HEAT-SCHED
                              COOL-TEMP-SCH    = COOL-SCHED

                              THERMOSTAT-TYPE  = PROPORTIONAL         $ DOE-2 DEFAULT
                              THROTTLING-RANGE = 2                    $ DOE-2 DEFAULT
                              BASEBOARD-CTRL   = OUTDOOR-RESET ..     $ DOE-2 DEFAULT

SPACE1-1  = ZONE              SIZING-OPTION    = ADJUST-LOADS         $ DOE-2 DEFAULT = FROM LOADS
                              ZONE-CONTROL     = CONTROL
                              ASSIGNED-CFM     = 1800                 $ 360 cfm/ton X 1ton/500sqft
                              ZONE-TYPE        = CONDITIONED          $ DOE-2 DEFAULT
                              BASEBOARD-RATING = 0.0000       ..      $ DOE-2 DEFAULT

S-CONT    = SYSTEM-CONTROL    MAX-SUPPLY-T     = 105                  $ DOE-2 DEFAULT
                              MIN-SUPPLY-T     = 55           ..      $ DOE-2 DEFAULT

S-AIR     = SYSTEM-AIR        VENT-METHOD      = S-G                  $ SHERMAN-GRIMSRUD METHOD, DOE-2 DEFAULT = AIR-CHANGE

                              DUCT-AIR-LOSS    = 0                    $ DOE-2 DEFAULT
                              DUCT-DELTA-T     = 0                    $ DOE-2 DEFAULT
                              MAX-VENT-RATE    = 20                   $ DOE-2 DEFAULT
```

```
                              HOR-VENT-FRAC    = 0                    $ DOE-2 DEFAULT
                              FRAC-VENT-AREA   = 0.5                  $ DOE-2 DEFAULT
                              NATURAL-VENT-AC  = 0                    $ DOE-2 DEFAULT
$                             NATURAL-VENT-SCH =                        DOE-2 DEFAULT = NO NATURAL VENT
$                             VENT-TEMP-SCH    =                        DOE-2 DEFAULT = HEAT-TEMP-SCH
                              ..

S-FAN     = SYSTEM-FANS       SUPPLY-DELTA-T   = 1.57826              $ TAKEN FROM IC3, DOE-2 DEFAULT = 0.396
                              SUPPLY-KW        = 0.00051              $ TAKEN FROM IC3, DOE-2 DEFAULT = 0.000128 kW/cfm
                              FAN-SCHEDULE     = FAN-SCHED     ..     $ DOE-2 DEFAULT = ALWAYS ON

SYST-1    = SYSTEM            SYSTEM-TYPE      = RESYS
                              SYSTEM-AIR       = S-AIR
                              SYSTEM-FANS      = S-FAN
                              SYSTEM-CONTROL   = S-CONT

                              COOLING-EIR      = 0.211695             $ COOLING EIR (EXCLUDING SUPPLY FAN), DOE-2 DEFAULT = 0.438
                              HEATING-EIR      = 0.236011             $ HEATING EIR (EXCLUDING SUPPLY FAN), DOE-2 DEFAULT = 0.37
                              ZONE-NAMES       = (SPACE1-1)
                              SUPPLY-CFM       = 1800                 $ 360 cfm/ton X 5 ton
                              HEAT-SOURCE      = HEAT-PUMP            $ FOR ASHP SYSTEM, DOE-2 DEFAULT = GAS-FURNACE
                              COOLING-CAPACITY = 60000                $ 5 tonS X (1 ton/12,000 Btu/h)
                              HEATING-CAPACITY = -60000               $ 5 tonS X (1 ton/12,000 Btu/h)

                              COOL-CAP-FT      = SDL-C1               $ DOE-2 DEFAULT
                              COOL-EIR-FT      = SDL-C11              $ DOE-2 DEFAULT
                              COOL-EIR-FPLR    = SDL-C16              $ DOE-2 DEFAULT
                              COOL-SH-FT       = SDL-C21              $ DOE-2 DEFAULT
                              COIL-BF          = 0.24                 $ DOE-2 DEFAULT
                              COIL-BF-FCFM     = SDL-C31              $ DOE-2 DEFAULT
                              COIL-BF-FPLR     = SDL-C120             $ DOE-2 DEFAULT
                              COIL-BF-FT       = SDL-C41              $ DOE-2 DEFAULT
                              COOL-FT-MIN      = 70                   $ DOE-2 DEFAULT
                              CRANKCASE-HEAT   = 0.05                 $ DOE-2 DEFAULT
                              CRANKCASE-MAX-T  = 50                   $ DOE-2 DEFAULT
                              OUTSIDE-FAN-MODE = INTERMITTENT         $ DOE-2 DEFAULT
                              COMPRESSOR-TYPE  = SINGLE-SPEED         $ DOE-2 DEFAULT
                              CONDENSER-TYPE   = AIR-COOLED           $ DOE-2 DEFAULT
                              RATED-CCAP-FCFM  = SDL-C76              $ DOE-2 DEFAULT
                              RATED-SH-FCFM    = SDL-C83              $ DOE-2 DEFAULT
                              RATED-CEIR-FCFM  = SDL-C91              $ DOE-2 DEFAULT
                              RATED-HCAP-FCFM  = SDL-C98              $ DOE-2 DEFAULT
                              RATED-HEIR-FCFM  = SDL-C105             $ DOE-2 DEFAULT
                              HEAT-EIR-FT      = SDL-C56              $ DOE-2 DEFAULT
                              HEAT-EIR-FPLR    = SDL-C61              $ DOE-2 DEFAULT
                              HEAT-CAP-FT      = SDL-C51              $ DOE-2 DEFAULT
                              MIN-HP-T         = 10                   $ DOE-2 DEFAULT
                              MAX-HP-SUPP-T    = 17                   $ DOE-2 DEFAULT
                              HP-SUPP-SOURCE   = ELECTRIC             $ DOE-2 DEFAULT
                              BASEBOARD-SOURCE = ELECTRIC             $ DOE-2 DEFAULT
                              SIZING-RATIO     = 1.0000               $ DOE-2 DEFAULT
                              EVAP-PCC-EFF     = 0.8000        ..     $ DOE-2 DEFAULT

HP-1      = PLANT-ASSIGNMENT  SYSTEM-NAMES     = (SYST-1)
                              HP-LOOP-HEATING  = FROM-SYSTEMS
                              HP-LOOP-COOLING  = FROM-SYSTEMS
                              DHW-SIZE         = 50                   $ 50 GALLONS (Henderson, 2008), DOE-2 DEFAULT = AUTOSIZING
                              DHW-GAL/MIN      = 0.0486               $ gal/min = ((30Xliving unit)+(10Xnumber of bedroom))/1440
                              DHW-SCH          = DHW-SCHED
                              DHW-INLET-T-SCH  = DHWINLETSCH-1
                              DHW-SUPPLY-T     = 120                  $ 2001 IECC (402.1.3.7)
                              DHW-HEAT-RATE    = 18766                $ 18,766 Btu/hr (Hendron, 2008), DOE-2 DEFAULT = AUTOSIZING
                              DHW-TYPE         = ELECTRIC             $ FOR ELECTRIC WATER HEATER, DOE-2 DEFAULT = GAS
                              DHW-EIR          = 1                    $ DOE-2 DEFAULT, FOR ELECTRIC WATER HEATER
                              DHW-LOSS         = 0.0065767053         $ TAKEN FROM IC3, (Lutz, 1998), DOE-2 DEFAULT = 0.03

                              DHW-EIR-FT       = DHWHPEIRFT           $ DOE-2 DEFAULT FOR HEAT-PUMP DETAILS ARE ON DOE-2.1E
SUPPLEMENT PAGE 3.61
                              DHW-HEAT-RATE-FT = DHWHPCAPFT           $ DOE-2 DEFAULT FOR HEAT-PUMP
                              DHW-EIR-FPLR     = DHWGEIRFPLR          $ DOE-2 DEFAULT FOR HEAT-PUMP
                              DHW-PUMP-ELEC    = 0                    $ DOE-2 DEFAULT
                              MAX-FLUID-T      = 120                  $ DOE-2 DEFAULT
                              MIN-FLUID-T      = 50                   $ DOE-2 DEFAULT
                              FLUID-VOLUME     = 15                   $ DOE-2 DEFAULT
$                             DHW-HSUP-RATE    =                        DOE-2 DEFAULT = AUTOSIZING
$                             DHW-HSTOR-RATE   =                        DOE-2 DEFAULT = AUTOSIZING
                              ..

END   ..

COMPUTE SYSTEMS   ..

$==================================== PLANT ====================================================

INPUT PLANT   ..

              PLANT-REPORT  SUMMARY = (ALL-SUMMARY)  ..

END  ..

COMPUTE PLANT   ..

STOP ..
```